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SHAKEDOWN & DETERMINATION OF TUNNEL CONTROL SETTINGS FOR REFURBISHED TRISONIC GASDYNAMIC FACILITY (TGF)

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14. ABSTRACT
The TGF had refurbishment completed in 2005 after being put into mothball status ten years prior. Upgrades during refurbishment to the tunnel and the loss of the old operations staff required the need for an initial set of tunnels runs to determine how to operate the facility, rediscover the limitations of the facility, and determine the correlation between the old documented control settings and the new systems. This control calibration also served as the initial shakedown of the refurbished tunnel, allowing technicians and engineers to cycle the systems and discover the best practices for operation and unresolved or unknown problems with the system. The shakedown initiated the reliable and successful operation of the TGF for future ground testing experiments.

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<u>List of ACRONYMS & Symbols</u>

AFRL	Air Force Research Laboratory
CFD	Computational Fluid Dynamics
DAQ	Data Acquisition
DTC	Digital Temperature Compensated
ESP	Electronically Scanned Pressure
FS	Factor of Safety (stress analysis) or Full Scale (measurement error)
g	Gravitational constant = 32.17 lbm * ft / lbf / s^2
Hp	Horsepower
L	Aerodynamic Reference (or model) Length
M	Mach number
MDoE	Modern Design of Experiments
mV	milliVolt
MW	megaWatt
PC	Personal Computer
PLC	Programmable Logic Controller
P_0	Total pressure ahead of the shock
P_s	Static pressure ahead of the shock
psf	Pounds per square foot (absolute)
PSI	Pressure Systems Incorporated
psi	Pounds per square inch
psia	Pounds per square inch absolute
psid	Pounds per square inch differential
PXI	PCI Extensions for Instrumentation
Q	Dynamic Pressure
R	Air gas constant = 1716 ft^2 / s^2 / °R
Re	Reynolds Number
RPM	Revolutions per minute
SARL	Subsonic Aerodynamic Research Laboratory
T_0	Total Temperature
T_s	Static Temperature
TGF	Trisonic Gasdynamic Facility
VAX	Virtual Address Extension
VWT	Vertical Wind Tunnel
WPAFB	Wright Patterson Air Force Base
γ	Air specific heat = 1.4
μ_x	Dynamic viscosity
ρ	Density of air

This report documents the Shakedown and Control Calibration experiment conducted from August 2005 through December 2005 in the AFRL TGF Wind Tunnel located at Wright-Patterson Air Force Base, Ohio. It contains detailed descriptions of the experiment set-up, operations, and tear down. Data results and analysis are included as appropriate. The purpose of the document is to record all pertinent information about this experiment. The information provides customers and planners with guidelines for similar tests that may be required in the future. It also provides the Experimental Fluid Dynamics team with lessons learned that will be used to improve experiment processes.

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FOREWORD

This technical experiment report summarizes the shakedown and control calibration of the TGF after it had undergone three years of refurbishment. This was an in-house project of the Air Force Research Laboratory, Air Vehicles Directorate. Technical contributions from the Propulsion Directorate of the AFRL were made during control calibration, which greatly improved the performance of the facility, making this testing successful. Key personnel on this experimentation included:

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1.0 REFURBISHMENT BACKGROUND

The TGF was built in the early 1950's as a supersonic research tunnel and operated successfully until it was shut down in Oct 1992. In 2002, it was decided to stand the facility back up & upgrade it. Refurbishment included building and control room improvements, overhaul of the compressor, replacement of the entire cooling system including the cooling coils, repair of the drive system, replacement of old electrical systems, and updates to the data & control systems to PC & PLC based systems from mercury anemometry, VAX computers and analog systems. Due to upgrades to the tunnel and loss of the old operations staff, an initial set of tunnels runs were necessary to determine how to operate the facility, rediscover the limitations of the facility, and determine the correlation between the old documented control settings and the new systems. This control calibration also served as the initial shakedown of the refurbished tunnel, allowing technicians and engineers to cycle the systems and discover the correct order of operations, any idiosyncrasies of the systems, and unresolved or unknown problems.

2.0 MODEL DESCRIPTION

The shakedown model, Figure 1, was a simple wedge with three flow angularity pressure taps. A similar model as used in the 1989 calibration of the TGF, but may have originally been built in 1952 for the original tunnel calibrations. The model used in 2005 was attached to an extension sting, Figure 2 and was mounted to the standard TGF crescent model support.

Figure 1. Flow angularity wedge used in shakedown and control calibration

Figure 2. 20-inch sting extension used to mount wedge model near center of test section

Data from flow angularity taps, collected only during supersonic runs, was not analyzed for the shakedown runs because the initial analysis shows inconsistent data, indicating a possible leak or problem with the pressure taps.

2.1 STRESS ANALYSIS SUMMARY

A stress analysis on the wedge model alone gives an ultimate factor of safety of 6.84 and a yield factor of safety of 5.89 at the maximum possible loading condition for the TGF. This occurs when the maximum total pressure, Mach 2.3 supersonic flow unstarts on one side of the model, giving a normal shock while the other side of the model still has an oblique shock. This condition creates a total pressure difference of 10.39psi which loads the model even higher than maximum dynamic pressure, 8.33psi. The factor of safety is well above the facility requirements of 3.0 for yield and 4.0 for ultimate strength. Therefore, the model was shown to be safe for all potential running conditions.

3.0 TEST FACILITY DESCRIPTION

The Trisonic Gasdynamic Facility (Figure 3), located in building 26 in area B of WPAFB, was built in 1952 as a supersonic facility. Today it provides ground testing capability for components and complete aircraft models in the subsonic and supersonic regimes to researchers within Air Force and Department of Defense organizations. When coupled, the 5000 Hp and 3500 Hp motors provide the power to this closed circuit wind tunnel to achieve test speeds of Mach 0.23 to 0.87, 1.5, 1.9, 2.3 and 3.0 through the use of five sets of nozzle blocks. Transonic and Mach 4.7 nozzle blocks also exist, but the capability to run the Mach 4.7 was lost due to the refurbishment and removal of a supporting facility. The transonic set is too complex to use and is also not currently operational. The tunnel total pressure ranges from 0.5 to 2.0 atmospheres, but is limited depending on Mach number. The maximum subsonic Reynolds number for the tunnel is 2.5×10^6 and the maximum subsonic dynamic pressure is 350psf (Ref. 1). The maximum supersonic Reynolds number is 5×10^6 and the maximum supersonic dynamic pressure is 1000 psf (Ref. 1). The stagnation temperature is designed to be held constant at 100ºF.

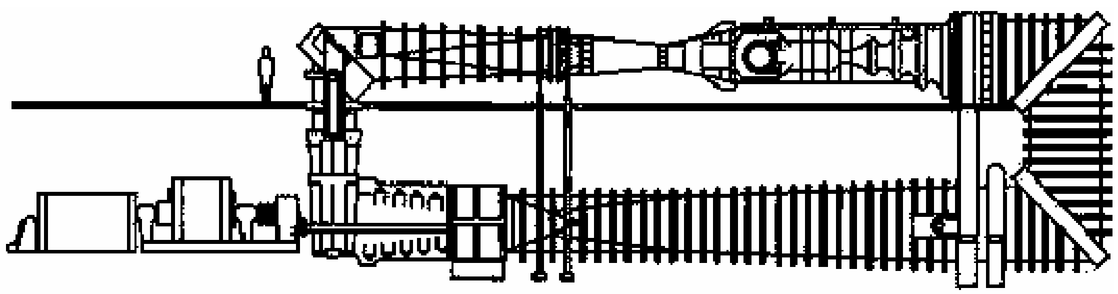


Figure 3. Trisonic Gasdynamic Facility

The test section is two feet high, two feet wide, four feet long with two flat 28-inch diameter viewing windows on either side wall. The primary model support, a crescent mounted sting, can be pitched -1° to +18.5° and rolled -90° to +180°. The TGF also has the capability to do half-span testing by removing one or both side windows.

4.0 TEST SET-UP

The shakedown had originally been designed to utilize Modern Design of Experiments (MDoE) in order to reduce the number of test points run and increase the reliability of the results. Due to the instability of the tunnel, especially supersonically, and with the uncertainty of settings, a more traditional design was utilized. This allowed the operators to determine what settings were necessary to establish on-condition flow. Additionally, an approach of changing variables independently and determining their effect allowed the power consumption at a given testing condition, denoted by Mach and total pressure, to be reduced. The full envelope of operation will be determined during flow quality calibration, which will follow tunnel shakedown. The initial runs were mimics of the original operator's manual settings to determine if these settings were highly model-specific or if they could be used as general settings for establishing flow. Based on the ability to start flow and stay on-condition, later based on the profile of the compressor and the location of the static wall pressure reduction, the settings of the tunnel were modified.

The wedge model was installed at one orientation, allowing Schlieren images to show the establishment of supersonic flow in the test section. The use of Schlieren also showed when the shock wave was not drawn into the second throat but was stationary in front of or just aft of the model.

Blockage wedges were also considered for use. Based on previous calibration reports and charts, it was assumed that these existed. Unfortunately those that did exist were mostly cones and flat cylinders up to 3 inches in diameter, as shown in Figure 4, and did not provide the amount of blockage that was desired to be examined.

Figure 4: Blockage cones of various sizes and angles

4.1 INSTRUMENTATION SET-UP

The TGF uses several software and hardware systems to collect data during each test. LabVIEW and Inertia are the two primary software systems used.

4.1.1 TGF DATA ACQUISITION SOFTWARE

A National Instruments LabVIEW based software package, INERTIA, is currently being used to acquire all model and basic tunnel condition data such as tunnel pressure, temperature and Mach number, as well as displaying all monitored channels real-time. INERTIA is configurable to accommodate virtually any new hardware additions required by a specific test such as thermocouples, analog or digital instrumentation, and model static or dynamic pressure measurements. All static pressure data is acquired separately through a Pressure System Instruments (PSI) 8400 which is also fully configurable in INERTIA.

4.1.2 TGF DATA ACQUISITION HARDWARE

All non-pressure instrumentation is acquired by National Instruments hardware. Currently, there are two systems: a Tunnel Circuit Monitoring system and the basic TGF Data Acquisition system (DAQ). The Tunnel Circuit Monitoring system involves remote Field point hardware and PSI 9016 Ethernet modules to monitor pressures in all regions of the tunnel, temperatures, dew point, second throat wall positions and limits, and compressor vane angles. The TGF DAQ system includes a single PXI rack of eight measurement modules connected to the Data PC through a fiber-optic link. These eight modules provide a variety of measurement types and can be easily swapped to accommodate specific test requirements, as well as expanded up to 20 modules for additional instrumentation channels. A single multiplexed Analog-to-Digital converter is used in this system to acquire all analog data at sampling rates up to 333 kiloSamples/sec with 16-bit accuracy performance. Model pressures are measured and acquired by the PSI 8400 system, which can be configured to support up to twelve 32- or 64-port electronically scanned differential pressure (ESP) modules. Two types of ESP modules are available: analog and Digital Temperature Compensated (DTC).

Using the analog modules, accuracy is between ± 0.05 %FS and ± 0.10 %FS without thermal compensation which, if exposed to varying temperatures, such as those inside of the tunnel or model, requires constant calibration while on-condition in order to provide minimal temperature effects. DTC modules provide continuous temperature monitoring of individual transducers which allows for real-time compensation of temperature changes through a ten temperature range by nine pressure factory calibration matrix. DTC modules provide fast and accurate pressure acquisition by eliminating the frequent calibration required by the analog modules. Full-scale accuracy is ± 0.03% on ranges greater than ± 2.5 psid and ± 0.06% on all ranges less than or equal to ± 2.5 psid, along with negligible temperature drift effects. Calibration for both types of modules is achieved through a process that the

PSI 8400 unit provides, with high accuracy calibration modules (PCU) installed in the rack unit. These calibration modules supply multiple pressures to the ESP modules through the 8400 backplane. Then the 8400 rack unit measures each individual transducer at each calibration point and calculates constants for a curve-fit based on the number of cal points. These constants are then stored within the 8400 for pressure conversion during acquisition cycles. Calibration of DTC modules only needs to occur every six months due to the factory temperature compensation constants stored within the module, when Analog modules require calibration on a temperature change due to long term non-linearity.

4.1.3 ESP MODULES

The primary pressure sensing instrumentation consists of an ESP module. Figure 5 shows the DTC version. This test used the DTC pressure modules. For subsonic testing, a ± 5 psid module was used and a ± 30 psid module was used for supersonic flows. These were contained outside of the model, below the mounting crescent, so that they were exposed to constant temperatures and were calibrated prior to each day of use. Each pressure module contains 32 separate transducers, but 64 port modules are also available. The transducers were referenced to the test section static pressure, which is sampled from just upstream of the test section window by a highly accurate SONIX digital transducer previously used in the TGF.

Figure 5: DTC ESP modules

4.1.4 CALIBRATOR

The TGF uses a Pressure Systems Incorporated calibrator, 8433 PCU shown in Figure 6, typically utilizing 5-psid and 45-psia resonating quartz crystal pressure standards. The calibration standards are component parts of the PSI 8400 Electronically Scanned Pressure system.

Figure 6: PSI Pressure Calibrators

4.2 UNCERTAINTY ANALYSIS

Due to the problem with the calibration and insufficient correction, a proper uncertainty analysis cannot be performed of the static and total pressure from the DAQ, see Section 8.1.1 for details. Therefore the Mach number and Reynolds number also cannot have an uncertainty calculated. The DAQ data from the shakedown should be compared to data from the flow calibration and used to evaluate accuracy of results.

Errors in the data were present not only for the calibration but also during certain test conditions. Test points taken during warm up can give no Mach number (labeled NaN) if the static pressure is higher than the total pressure. For 11/28/06 to 12/08/06, temperature measurements taken cannot be used due to the failure of the tunnel total temperature thermocouple, giving either 0°R or a value above 6491°R. As shown in the equations in Section 5.1, these two errors give several other values, such as Reynolds number invalid results.

All other measurements taken during the shakedown, such as pressures through the compressor and temperatures throughout the tunnel, were for qualitative or evaluation purposes and while they were also calibrated, the uncertainty is not critical to operation and is not documented here.

5.0 TEST INFORMATION

The study to find out how to control TGF was done because the tunnel had a new crew that was inexperienced with the operation of the facility and because of the modifications done to the tunnel. Data from all parts of the tunnel were recorded by the tunnel circuit monitoring system to determine how to establish flow, show the profiles of performance, and monitor system's response to various inputs. They were recorded in tab-delimited format, labeled with parameter names as shown in Table D-1, Appendix D. The voltage from the wall positioning pots was calculated into position, measured in inches from centerline of the tunnel, which was based on a calibration done during refurbishment. Along with data from the INERTIA DAQ and the power consumption data from the tunnel control system, this gave a full view of how the tunnel configuration influences its performance.

5.1 TEST DESCRIPTION

The test was run by varying the tunnel control parameters, including compressor vane angle, bypass, and diffuser wall settings. Table 1 gives an example of the combination of parameters used in the runs.

The data from the DAQ was reduced to automatically calculate Mach, dynamic pressure, and Reynolds number from the static and total pressure and tunnel temperature:

$$M = (5\,(P_0 / P_s)^{2/7} - 5)^{1/2} \qquad [1]$$

where:

M	=	Local Mach number
P_0	=	Total pressure ahead of the shock
P_s	=	Static pressure ahead of the shock

$$Q = 0.7\, P_s\, M^2 \qquad [2]$$

where:

Q	=	Dynamic Pressure

$$Re = \rho\,(M\,(\gamma R T_s)^{1/2})\, L / (g\,\mu_x) \qquad [3]$$

where:

R	=	Air gas constant	= 1716 $ft^2 / s^2 / °R$
γ	=	Air specific heat	= 1.4
ρ	=	Density of air	[lb / ft^3]
μ_x	=	Dynamic viscosity	[$lbf * s / ft^2$]
T_s	=	Static Temperature [°R]	
Re	=	Reynolds Number	
g	=	Gravitational constant	= 32.17 $lbm * ft / lbf / s^2$
L	=	Aerodynamic Reference (or model) Length [ft] = 0.00694 ft (as calculated from results)	

Internal calculations give T_s, μ_x and ρ the results of which are directly put into Equation 3.

$$T_0 / T_s = 1 + M^2 (\gamma - 1) / 2 \qquad [4]$$

where:

T_0 = Total Temperature [°R]

$$\mu_x = 2.27 * 10^{-8} T_s^{3/2} / (T_s + 198.6) \qquad [5]$$

$$\rho = P_s / 53.34 / T_s \qquad [6]$$

Table 1. Sample run schedule with tunnel control parameters and recorded outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility August 31, 2005
Subsonic Calibration - Shakedown of Facility

		Independent Variables			Response Variables					Comments	Voltage 2400	Voltage 6900	
Data Point	Test Set Point	Pressure [psf]	Set Mach Number	Bypass	Vane Angle	Current on 3500 [Amps]	Current on 5000 [Amps]	Actual Mach	Actual Mach (II)	Start Run Prep 0900 Sync 1019 Shutdown 1124	Power 3500 [kW]	Power 5000 [kW]	Total Power [MW]
2	1	500	0.3	Open	-20	400	40	0.29	0.3	Walls Open at TSPt 1 ONLY	960	276	1.24
3		500	0.3	Open	-20	387	39	0.27	0.27	Walls: 1&2, 3&4, 5&6	929	269	1.20
4	2	500	0.3	1/2	-20	386	40	0.31	0.31	14.49 & 14.52	926	276	1.20
5	3	500	0.3	Closed	-20	385	40	0.34	0.33	14.38 & 14.36	924	276	1.20
6	6	500	0.4	Closed	-16.6	382	53	0.4	0.4	14.55 & 14.56	917	366	1.28
7	9	500	0.5	Closed	-12.2	392	75	0.5	0.49		941	518	1.46
8	12	500	0.6	Closed	-9.4	392	95	0.6	0.6		941	656	1.60
9	15	500	0.7	Closed	-4.5	389	108	0.7	0.69		934	745	1.68
	18	500	0.8	Closed						Vane @ +5: No change			
					-20	380	100		0.33	So unload & go to next.	912	690	1.60
10	21	1000	0.3	Closed	-20	379	156	0.33	0.33		910	1076	1.99
11	24	1000	0.4	Closed	-16.6	385	186	0.39	0.39		924	1283	2.21
12	27	1000	0.5	Closed	-11.6	389	235	0.5	0.5		934	1622	2.56
13	30	1000	0.6	Closed	-8.8	380	274	0.6	0.6		912	1891	2.80
14	33	1000	0.7	Closed	-3.6	381	294	0.7	0.69		914	2029	2.94
15	36	1500	0.3	Closed	-20	389	271	0.32	0.33		934	1870	2.80
16	39	1500	0.4	Closed	-15.6	389	337	0.41	0.41		934	2325	3.26
17	42	1500	0.5	Closed	-11.8	450	367	0.5	0.49		1080	2532	3.61

The raw data from the tunnel circuit monitor systems was also utilized to determine location of shocks, compressor profile (Figure 7) and tunnel temperature (Figure 8). The data from the compressor became critically important to establishing supersonic flow and achieving higher subsonic Mach numbers. The data was also used to determine problems with the system, such as climbing temperatures in the system, which indicated problems with subsystems. Power consumption, while not a part of the DAQ or the tunnel circuit monitoring system, was collected at various times to determine if one setting was more efficient than another. If the setting was not efficient, how much extra power was being drawn could be determined. This was also important for determining what pressure and Mach numbers could be achieved if there was a limited power supply, such as often is the case while operating on first shift.

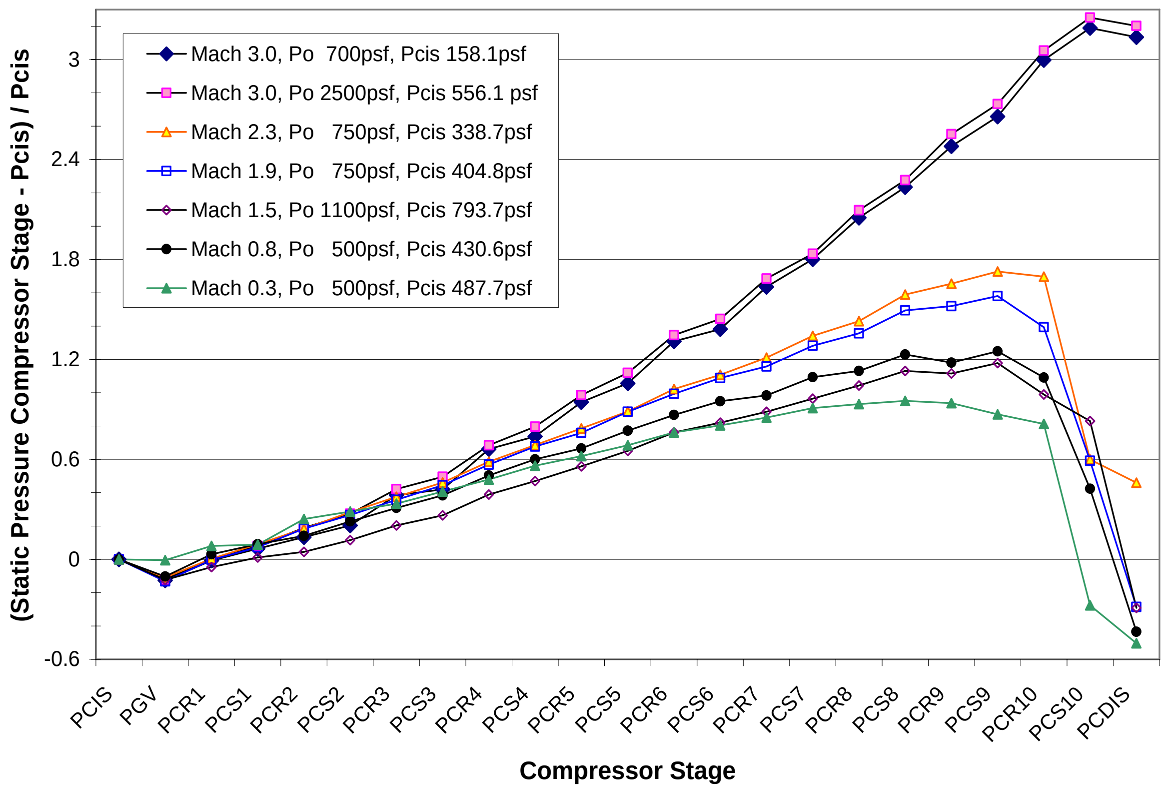


Figure 7. Compressor profile for all supersonic and selected subsonic Mach numbers

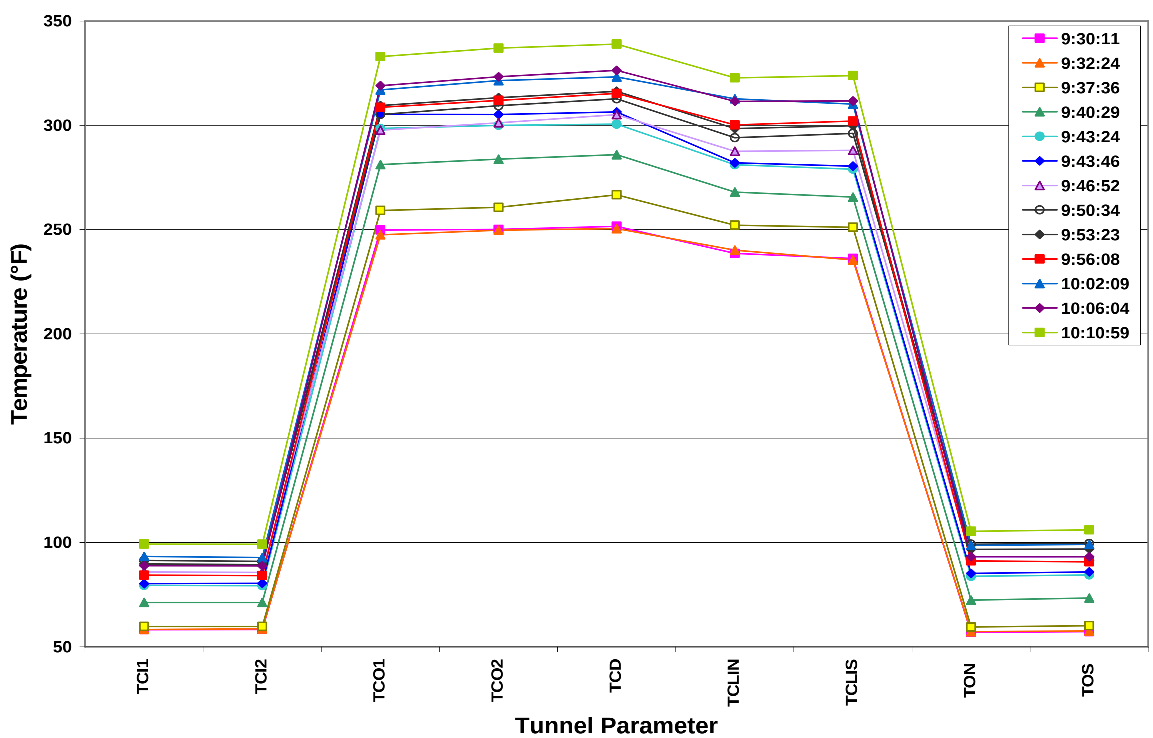


Figure 8. Sample temperature profiles during first half hour of on-condition at Mach 2.3

5.2 TEST NOTES

From 31 August through 14 December 2005, the TGF operations team completed the entire shakedown and control calibration on day shift with only sixteen days of experimentation. The shakedown provided an opportunity for the TGF operations team to learn to identify conditions that indicated best-practices operation, such as the profile of the compressor. The operations efficiency was low due to several factors: power limitations, the inability to run simultaneously with other facilities such as SARL, the time it took to change nozzle blocks and the evaluating of data and then planning the next runs based on the evaluation. There was also a significant repair of a seal in the liquid rheostat system which consumed eight days to repair and approximately two and a half days of delays during operations. The control calibration ran through the full Mach range of the subsonic nozzle block and each of the four supersonic blocks. During attempts to reach high subsonic conditions, difficulties led the team to request assistance from Doug Rabe and Jason Parson, both of whom have expertise in the operation of compressors. Their assistance led to the ability to maximize the subsonic Mach number of 0.87 and allowed the team to work on the profile independently to achieve flow supersonically. To establish supersonic flow, also referred to as getting “on-condition”, the compressor vanes, bypass and secondary throat walls had to be manipulated. Schlieren was used to determine when supersonic flow was established. An example of “on-condition” verses “off-condition” is given in Figure 9. In the right image, the normal shock (white arrow) is still upstream of model prior to being swallowed into diffuser. Expansion waves seen on the model (black arrow) but are not stable as the shock waves are as seen in the on-condition flows. Off-condition could also be achieved by opening the bypass, allowing the shock to stand near the nozzle. If the shock did not travel down the test section when the bypass valve was closed, expansion waves on the model, as shown in Figure 9, could be seen without the strong shock lines associated with being on-condition. Additionally, the team learned to hear problems with the TGF, particularly when supersonic flow was not establishing in the test section and when the vacuum pumps, which control the tunnel total pressure, were cycled.

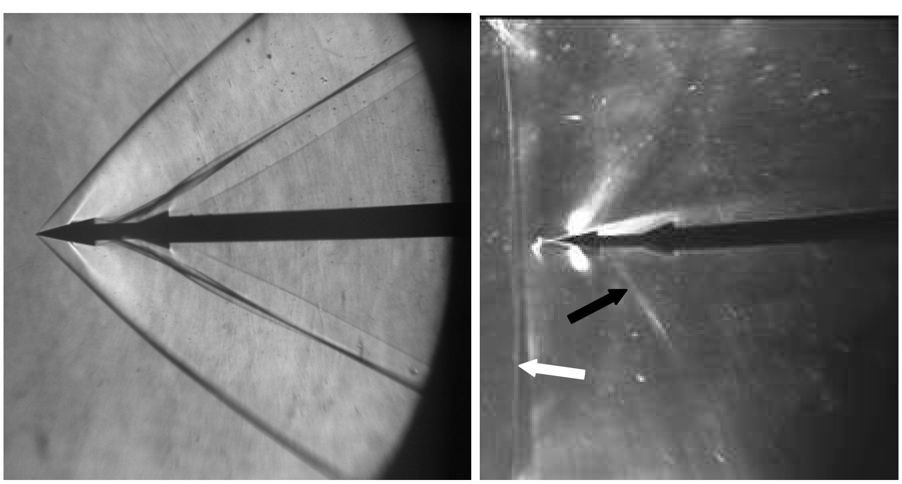


Figure 9. Schlieren of tunnel “on-condition” at Mach 3.0 (left) and “off-condition” at Mach 1.9 (right)

6.0 TUNNEL CONTROL

The TGF facility is a complex wind tunnel to operate and requires controlling several parameters. The control calibration's main intent is to discover what settings and parameters need to be varied in order to operate the facility. These settings have been recorded for previous operational runs but the validity of those settings needed to be verified.

6.1 CONTROL VARIABLES

Although several parameters such as humidity and nozzle block also determine the quality and ability to achieve on-condition flow, the following parameters of the tunnel operation have the most significant impact on the control of the flow.

6.1.1 TOTAL PRESSURE

Total pressure in the TGF is limited by the vacuum capacity of the vacuum pumps and the air compressors, such as the Worthington, which are balanced to maintain the set pressure condition. Since the pressure is constantly being balanced between above atmospheric pressure from the compressor and the vacuum system, there is some variance during operation. This variation is more significant when low pressures such as 500 psf are being maintained. A slight variation in pressure translates to a variation in the Mach number. While on and off-condition, the total pressure has a major impact on the power being drawn by the compressor. In turn, the range of pressure at any given Mach number is limited by the power limits of the motors. Measurement of the total pressure is most accurate on the DAQ system, though it is also measured on the control system and the tunnel circuit monitoring system. Additionally, it was noted that it was sometimes easier to establish flow at slightly elevated total pressures, such as 700psf rather than the 500psf at which the motors are synchronized. This, though, puts greater loads on the models. The maximum pressures achievable for each Mach number will be fully explored in the flow calibration.

6.1.2 COMPRESSOR: VANES & PRESSURE PROFILE

Only second to the nozzle blocks, no other component has more influence on the control of the tunnel than the compressor vanes. Subsonically, the vane settings produce the various Mach numbers. Supersonically, the compressor drives the flow and overcomes the pressure losses due to expansion and separation over the model and through the tunnel, shocks and frictional head loss. The compression profile, as shown Figure 7, is critical to the operation of the facility and the amount of power it draws. The vane settings determined from the control calibration are given in Table 2. The actual angle settings are given as well as any offsets since the tunnel input for adjusting other vane stages from the nominal setting is through use of offsets. There are several settings listed for each Mach because each allowed the tunnel to operate on-condition with the wedge model. These are considered a starting point for determining the vane configuration(s) needed with different models, which will induce different pressure losses.

6.1.3 DIFFUSER WALLS

The wall settings were also important for establishing flow in the tunnel. The three wall segments that make up the diffuser or second throat limit the flow and minimize the pressure loss from the recovery shock for supersonic flow. The top view of Figure 10 shows the diffuser walls in the closed position. This is the position for running model changes. Figure 11 shows the range of the possible diffuser wall settings and the cross sections for the various nozzles blocks. Cross section D is minimum nozzle throat area, section F is the end of first diffuser wall, section G is the end of the second diffuser wall, and section H is the end of the third diffuser wall. Due to the large range for the diffuser walls, the initial settings were selected from historical documentation from previous operation runs of the TGF. These initial settings are given in Table 3. Mach 3.0 had several settings so the three most common were selected.

The current method of measuring the wall setting, as shown in Figure 12, is from the tunnel centerline. The historical method is from the maximum or “open” position of the walls. For subsonic flow, the maximum Mach number was limited by the diffuser walls. So, as shown in the final settings in Table 4, the walls were moved to the open position to get the maximum flow possible.

According to Heppe (Ref. 2), who investigated the theoretical and experimental “minimum area relation for starting a supersonic tunnel” and “the amount by which the second throat may be reduced after the tunnel has been started”, noted that the theoretical minimum matched the actual within 3 percent but that only a third of the predicted reduction was realized before separation of the boundary layer. Similar to Heppe’s research, attempts were made in the TGF to optimize the wall settings after flow had been established. A minimum value at which the flow would breakdown was not reached. It may have been due to hesitancy to purposely unstart the tunnel due to the loading that would be induced on the compressor and the diffuser walls. A more in-depth investigation of the minimal position of the diffuser walls will be investigated during the flow calibration. Differences between the TGF and Heppe’s research should be noted here. The TGF has a more complex flow than Heppe’s research due to the wedge model and the model support. Additionally, the TGF does not have Schlieren or total pressure measurements aft of the test section. Static wall pressure taps in the diffuser do give an indication of the location of pressure recovery.

During investigation into the wall settings, it was noted that the compressor setting could have a significant impact on the pressure profile through the diffuser, sometimes even more than the walls themselves had as shown in Figure 13. Some of this can be explained through Heppe’s research. Heppe’s Schlieren images, as shown in Figure 14, showed that the position of the shock waves changed due to the height of the second throat. But in Heppe's research, this led to flow separation and tunnel un-start. This did not occur in the TGF, likely because the walls were never reduced to that point.

Table 2. Vane settings for establishing on-condition flow

Mach	**Vane Angle** (all unless denoted)
Mach 0.3	-20°
Mach 0.4	-16.6°
Mach 0.5	-12.4°
Mach 0.6	-9.5°
Mach 0.7	-4.5°
Mach 0.8	0° to 5°, guide vane -10° (offset: -10° to -5°)
Mach 0.87	5°, guidevane -10° to -15° (offset -15° to -20°) vane #1 0° to -5° (offset -5° to -10°)
Mach 1.5	5°, guide vane -20° (offset -25°) vane #1 -10° (offset -15°)
	5° guide vane -15° (offset -25°) vane #1 -5° (offset -25°) vane #9 15° (offset -25°) vane #10 15° (offset -25°)
	5° guide vane -15° (offset -20°) vane #1 -10° (offset -15°) vane #9 -2.5° (offset -7.5°) vane #10 10° (offset +5°)
	5° guide vane -15° (offset -20°) vane #1 0° (offset -5°)
	5° guide vane -10° (offset -15°) vane #1 -5° (offset -10°)
	5° guide vane -15° (offset -20°) vane #1 -10° (offset -15°)
Mach 1.9	5° guide vane -15° (offset -20°) vane #1 -10° (offset -15°) vane #9 0° (offset -5°) vane #10 0° (offset -5°)
Mach 2.3	5° guide vane 0° (offset -5°)
	5° guide vane -5° (offset -10°)
	5° guide vane 0° (offset -5°) vane #10 0° (offset -5°)
	5° guide vane 0° (offset -5°) vane #9 0° (offset -5°) vane #10 0° (offset -5°)
	5° guide vane 0° (offset -5°) vane #9 0° (offset -5°) vane #10 -5° (offset -10°)
	5° guide vane 0° (offset -5°) vane #1 0° (offset -5°) vane #9 0° (offset -5°) vane #10 -5° (offset -10°)
	5° guide vane -4.5° (offset -9.5°) vane #1 0° (offset -5°)
Mach 3.0	15° guide vane -10° (offset -25°) vane #1 -5° (offset -20°)

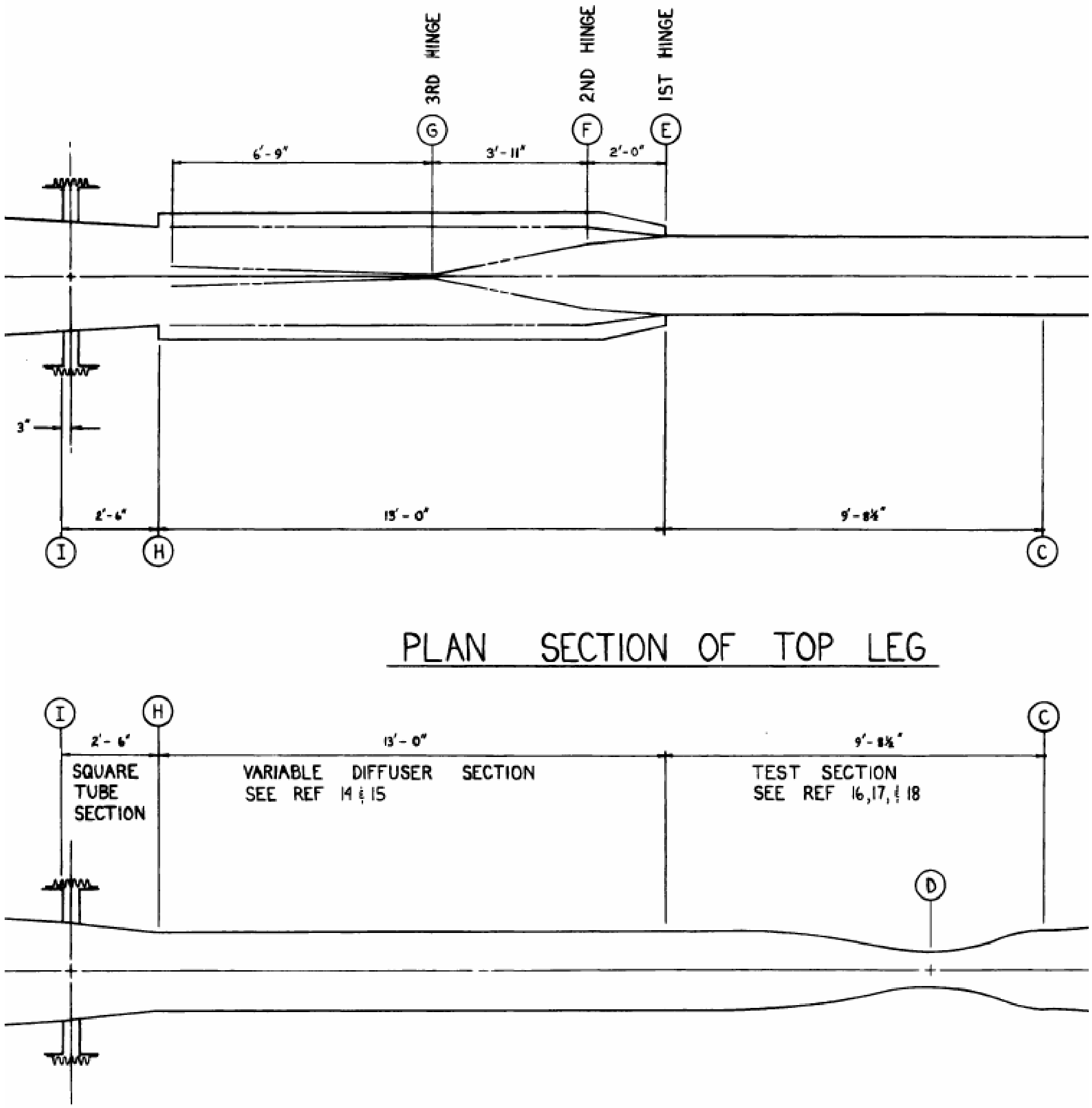
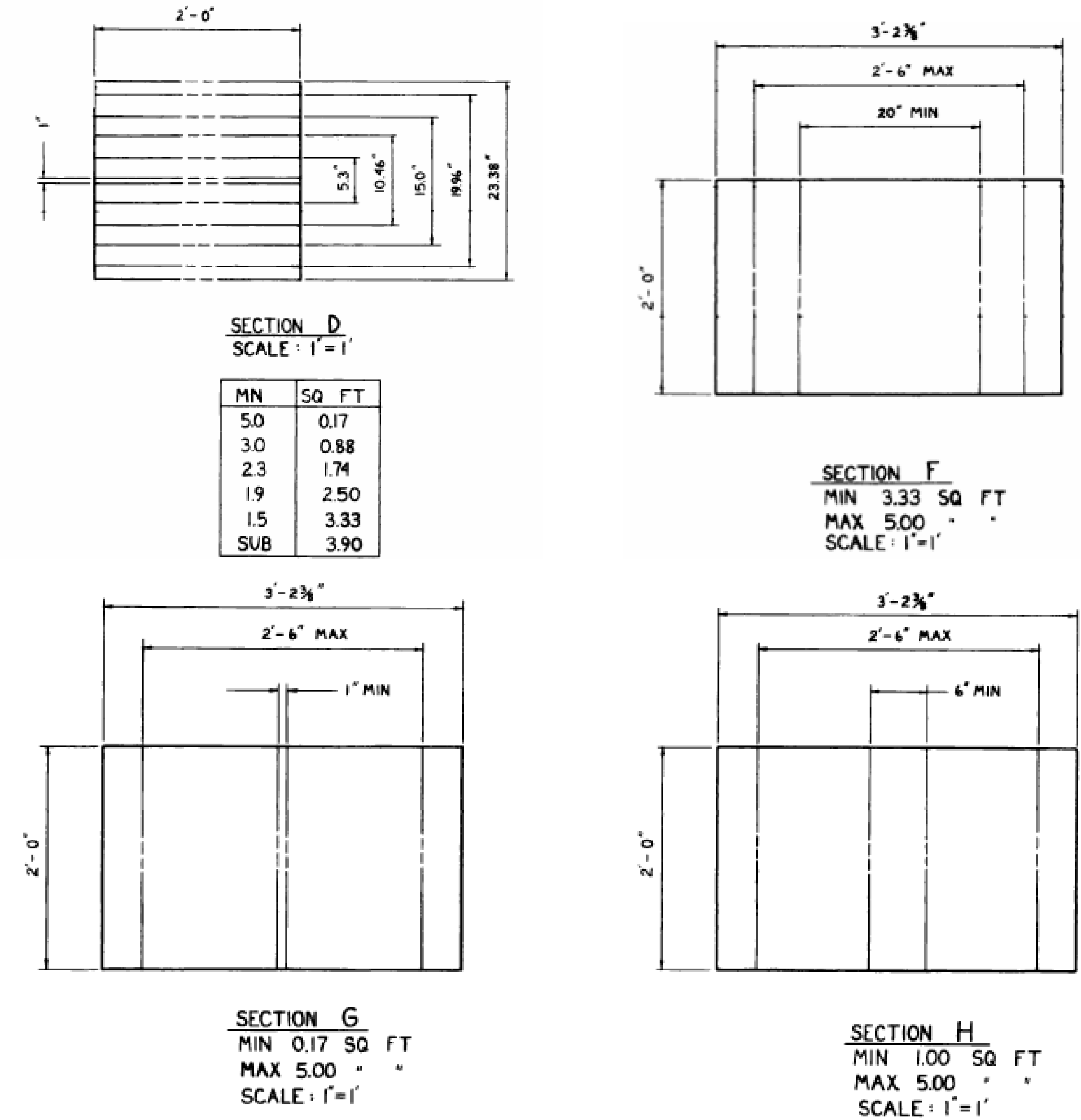


Figure 10. Top view (top) and side view (bottom) of TGF nozzle, test section and diffuser.



MN	SQ FT
5.0	0.17
3.0	0.88
2.3	1.74
1.9	2.50
1.5	3.33
SUB	3.90

Figure 11. Cross sectional areas of tunnel as labeled in Figure 10.

Table 3. Initial wall settings based on historical settings

Mach	Historical Settings	New Settings
Subsonic	0.5, 0.5, 0.5	14.5, 14.375, 14.875
Mach 1.5	1.5, 1.5, 1.4	13.5, 13.375, 13.975
Mach 1.9	3.8, 4.2, 2.0	11.2, 10.675, 13.375
Mach 2.3	2.5, 4.4, 2.3	12.5, 10.475, 13.075
Mach 3.0	4.5, 5.0, 5.0	10.5, 9.875, 10.375
Mach 3.0	4.64, 6.0, 6.0	10.36, 8.875, 9.375
Mach 3.0	4.86, 7.2, 6.5	10.14, 7.675, 8.875

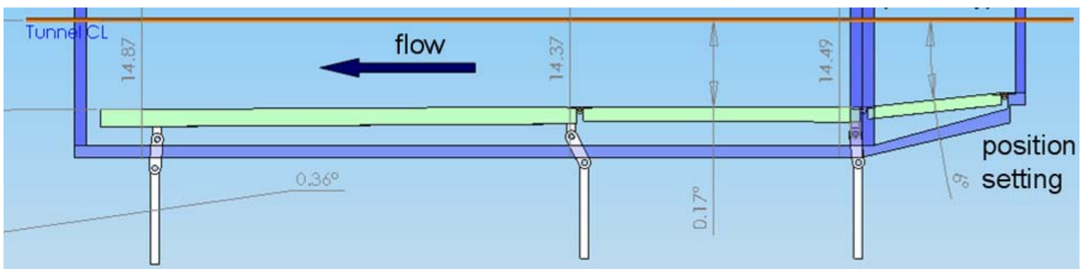


Figure 12. New subsonic diffuser wall settings as shown on three segments.

Table 4. Final wall settings based on control calibration

Mach	Diffuser Walls				
Subsonic	open				
Mach 1.5	13.5, 13.6, 13.6	13.8, 13.7, 13.7	14, 13.9, 13.9	13.8, 13.8, 14	14.5, 14.5, 14.6
	13.4, 13.3, 13.3	13.2, 13.1, 13.1			
Mach 1.9	11.2, 10.4, 13				
Mach 2.3	12.5, 11.1, 11.6	12.5, 10.6, 11.6	12.5, 10.6, 12.7		
Mach 3.0	11, 10.5, 10.5	10.3, 8.5, 8.5	10.2, 8.1, 10.6	10.2, 7.8, 8.5	10.2, 9, 9

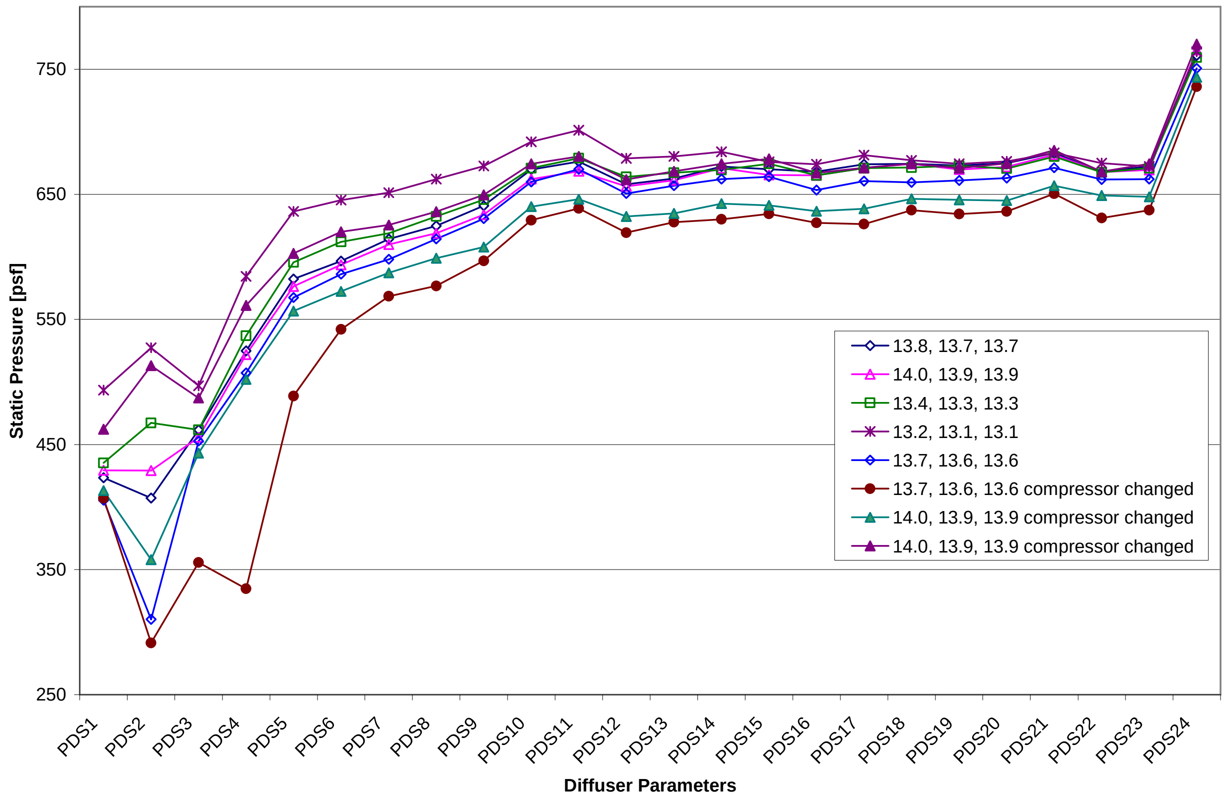
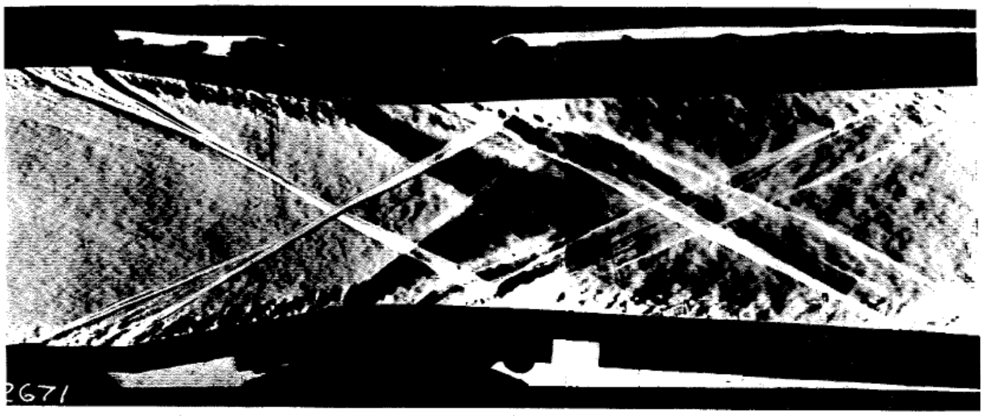
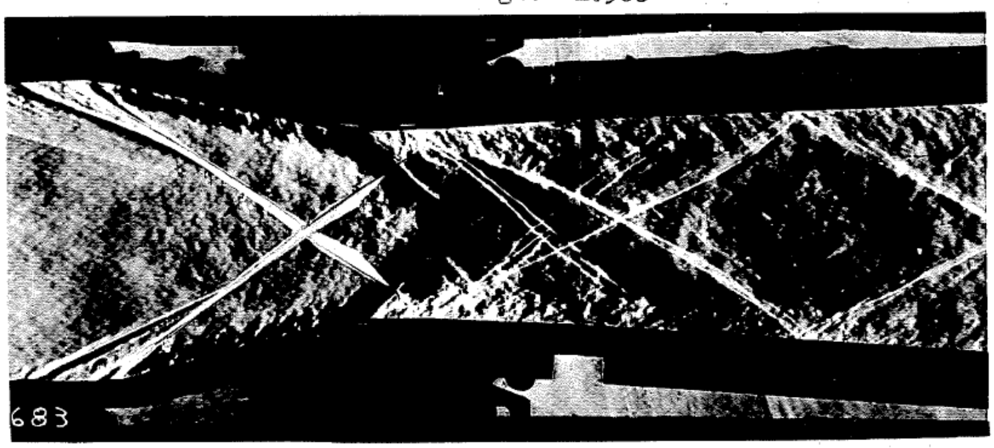


Figure 13. Vane change verses wall change on diffuser pressure profile



Second Throat Height 1.500



Second Throat Height 1.300
Flow Broke at 1.290

Figure 14. Schlieren images of reduction of diffuser from Heppe (Ref.2)

6.1.4 BYPASS

In the historical records of the TGF operation, the bypass setting was given, particularly for subsonic and Mach 3.0. To correlate these old setting numbers to the new system, the range of the old control was determined and re-distribute to the new control system, which is controlled by a 4 to 20 mV switch and displayed on the control panel by percentage open. Assistance from notes such as “mid” on the historical operation notes helped determine these settings. Based on this, Table 5 was generated. Although historical settings of 8 or “mid” were somewhat common in Mach 3 operation, during the shakedown operation, though, it was found that the bypass was needed to be completely closed. The bypass does need to be opened partially for the lowest subsonic Mach numbers when the motors are synchronized. For large blockages or high total pressure in the future, it might be feasible that the bypass may need to be opened to reduce the pressure losses.

Table 5. Bypass correlation between historical and new control systems

old sys.	0	2	4	6	8	10	12	14	16	18	20
new sys.	4	5.6	7.2	8.8	10.4	12	13.6	15.2	16.8	18.4	20
bypass % open	0	10	20	30	40	50	60	70	80	90	100

6.2 STANDARD OPERATION

During operation of the tunnel, a basic set of tunnel controls should be initially used. These settings will likely change over time with operation experience and knowledge of the influence of blockage and shock formations, but Table 6, a chart of the combination of the separate tunnel settings, lists the settings generated from the operation of the TGF during the shakedown.

During shakedown and control calibration, operation between settings was mainly off-condition to determine where flow could be established. During Mach 3.0 operation, the flow was difficult to reliably establish and therefore exploration began looking at how conditions could be changed while on-condition. This will be explored more in-depth during the flow calibration.

6.3 COMPARISON TO PREVIOUS TESTS

During preparation for the shakedown, research into previous calibrations and experiments performed in the tunnel was completed. These calibrations were mainly flow calibrations, but the settings used for their operation as well as the settings for numerous other tests are a critical point of comparison for the operation of the tunnel. During past operation of the tunnel, it was found that the vanes were used as independent stages with different angle settings. Likewise we discovered the same thing was necessary to operate the facility through investigation of the compressor profile. But the data on this is limited to just a few sheets from 19-20 Dec 1983, as shown by the re-creation of this data in Table 7.

These settings did not provide the Mach flows as the document noted. This may be due to blockage but it may also be due to the calibration of the vanes and what kind of pressure profile was needed for this test. In Figure 15, the data collected in 2005 from Figure 7 is compared to the original compressor pressure profile documented.

The differences at the Mach 2.3, 1.9 and 1.5 conditions show the potential need for further improvement in the vane settings for those conditions, especially to eliminate the lower compression ratio of the Mach 1.5 settings throughout most stages. This lowered compressor profile for Mach 1.5 may account for some of the initial difficulty establishing flow.

Table 6. Tunnel settings for establishing flow in TGF

Mach	Bypass	Diffuser Walls	Vane Angle (all unless denoted)
Mach 0.3	open to 50%	open	**-20°**
Mach 0.4	closed	open	**-16.6°**
Mach 0.5	closed	open	**-12.4°**
Mach 0.6	closed	open	**-9.5°**
Mach 0.7	closed	open	**-4.5°**
Mach 0.8	closed	open	**0° to 5°**, guide vane **-10°**
Mach 0.87	closed	open	**5°**, guide vane **-10° to -15°**, vane #1 **0° to -5°**
Mach 1.5	closed	13.5, 13.6, 13.6	**5°**, guide vane **-20°**, vane #1 **-10°**
		13.8, 13.7, 13.7	**5°**, guide vane **-15°**, vane #1 **-5°**, vane #9 **15°**, vane #10 **15°**
		14, 13.9, 13.9	**5°**, guide vane **-15°**, vane #1 **-10°**, vane #9 **-2.5°**, vane #10 **10°**
		13.4, 13.3, 13.3	**5°**, guide vane **-15°**, vane #1 **0°**
		13.2, 13.1, 13.1	**5°**, guide vane **-10°**, vane #1 **-5°**
		13.8, 13.8, 14	**5°**, guide vane **-15°**, vane #1 **-10°**
		14.5, 14.5, 14.6	
Mach 1.9	closed	11.2, 10.4, 13	**5°**, guide vane **-15°**, vane #1 **-10°**, vane #9 **0°**, vane #10 **0°**
Mach 2.3	closed	12.5, 11.1, 11.6	**5°**, guide vane **0°**
		12.5, 10.6, 11.6	**5°**, guide vane **-5°**
		12.5, 10.6, 12.7	**5°**, guide vane **0°**, vane #10 **0°**
			5°, guide vane **0°**, vane #9 **0°**, vane #10 **0°**
			5°, guide vane **0°**, vane #9 **0°**, vane #10 **-5°**
			5°, guide vane **0°**, vane #1 **0°**, vane #9 **0°**, vane #10 **-5°**
			5°, guide vane **-4.5°**, vane #1 **0°**
Mach 3.0	closed	11, 10.5, 10.5	**15°**, guide vane **-10°**, vane #1 **-5°**
		10.3, 8.5, 8.5	
		10.2, 8.1, 10.6	
		10.2, 9, 9	
		10.2, 7.8, 8.5	

Table 7. "Unusual" vane settings showing angle variation between stages from 19-20 Dec 1983

Attempted Mach	GV	vane1	vane2	vane3	vane4	vane5	vane6	vane7	vane8	vane9	vane10
0.6	1.75	0.5	-0.75	-3.375	-1.75	-0.5	-1.5	-3.0	-1.75	2.5	-2.75
0.7	7.75	5.0	5.0	1.5	2.625	5.13	2.75	1.5	3.0	10.125	1.75
0.8	12.5	8.75	9.75	6.0	7.375	10.5	7.0	7.25	7.25	18.5	6.0

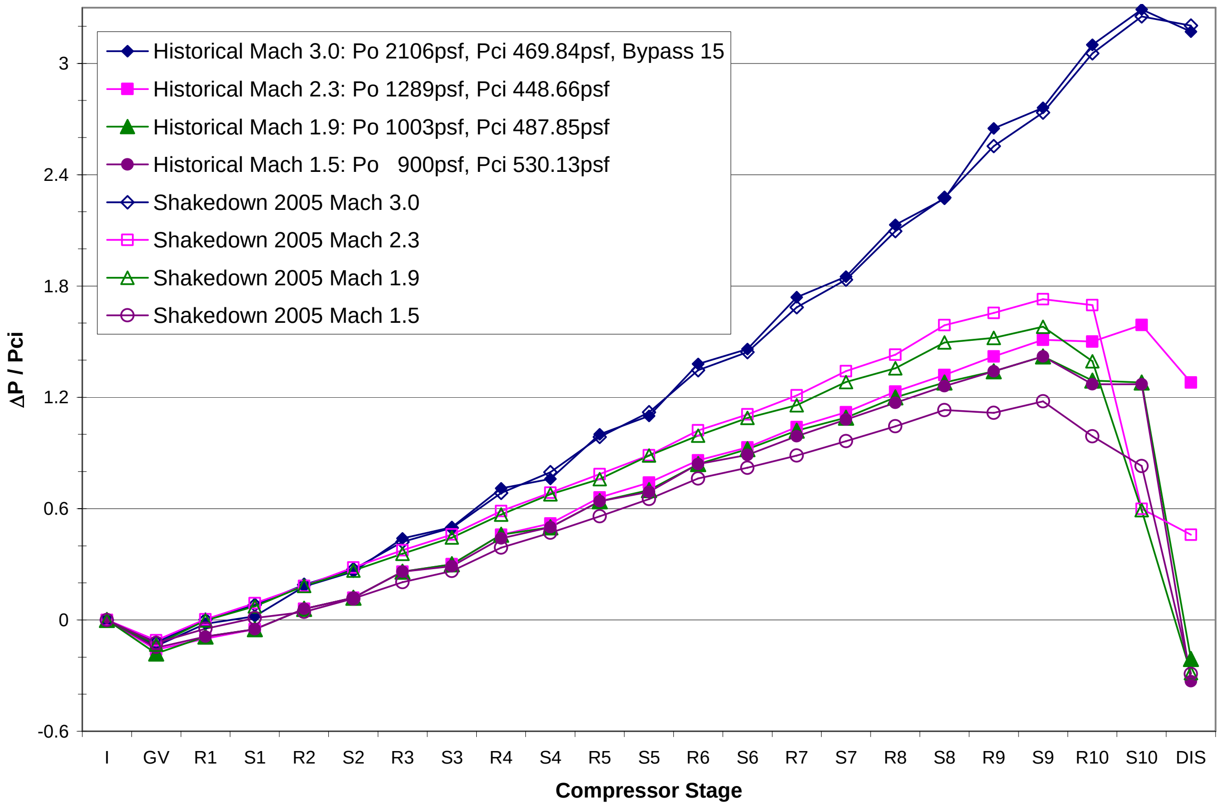


Figure 15. Compressor profile from historical documents compared to shakedown.

7.0 SUBSYSTEM OPERATIONS

Although the subsystems operation did not have a direct effect on the ability to establish flow, they are critical to the operation of the facility. Since this is not only a document giving the results of the control calibration, the operations of the subsystem is mentioned here as a part of the tunnel shakedown.

7.1 COOLING SYSTEM

The cooling system had been fully replaced and upgraded during refurbishment. During operations, the system control software was not fully operational so the control valve was kept open during all operations. This forced the system to be cooling at 100% capacity, even when this was necessary. Due to this excessive cooling, temperature was maintained around 70°F rather than the traditional 100°F. This is shown in Figure 16 which is a continuation of the data run in Figure 8 but near the end of the day after the cooling system had been forced on for more than an hour. Figure 8 also represents the temperature increase that was occurring prior to forcing the system to full capacity. Having this reduced temperature did not adversely affect the operation of the tunnel or establishment of flow. Of additional note, the temperature sensor between the cooling coils in the vertical return section of the tunnel may be shorted and was not providing data which could have shown the efficiency of the system.

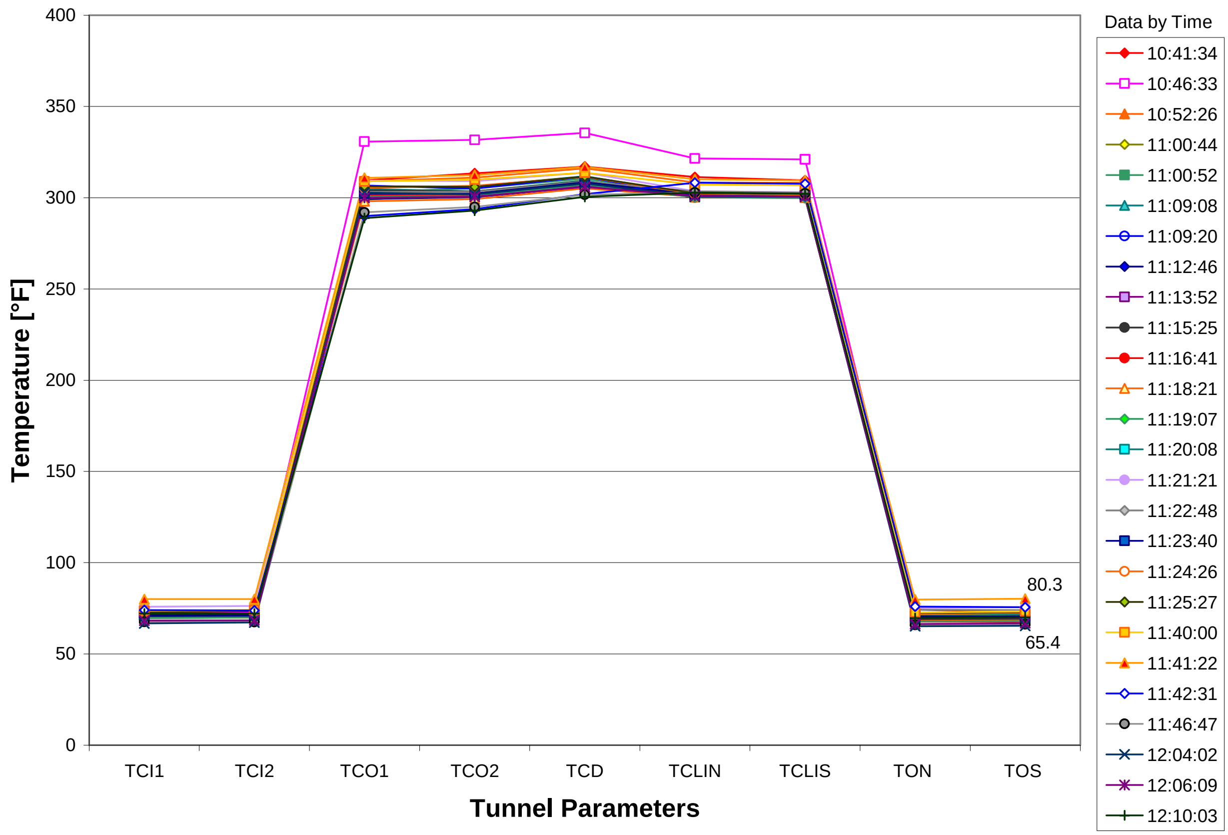


Figure 16. Constant temperature maintained by cooling system at full capacity.

7.2 AIR COMPRESSORS

The Worthington and Ingersol Rand air compressors provide the pressurized air to maintain total tunnel pressure. During initial operation of the facility, only the Ingersol Rand compressor was used. This created long delays when increasing pressure. This was especially true for running model changes which require the pressure to be increased from running condition, which was typically 500 or 700 psf, to approximately atmospheric pressure, 2100psf. After the Worthington compressor was added to operations, the time to increase pressure was less than half of what it was with the one compressor.

7.3 VACUUM PUMPS

During operation, problems with the vacuum pumps' cooling water and overheating were noted. These problems were planned to be corrected after shakedown operations. Part of these problems may be due to using these pumps for the first time since installation. These pumps had been installed but not operated just prior to the shutdown in the 1990's. They were to provide a vacuum system that was centralized in the building and not run and monitored from another building as the previous system had been. Two of the vacuum pumps run the most became more stable as testing progressed. At low total pressures, the pressure is more difficult for the system to maintain. Temporary decreases or the total pressure cyclically varying around the set point was noted on the graphical display of pressure of the DAQ system. This could lead to the measured Mach temporarily varying and creating a greater uncertainty of data. When cyclical pressure variation was noted, the data was attempted to be collected at approximately the same point within the cycle to reduce this error.

7.4 MOLECULAR SIEVE DRIER

During refurbishment of the TGF, the molecular sieve drier had the desiccant replace and the heating element housing repaired, and slightly modified. The heating element housing had broken seams and was poorly designed for the uniform distribution of heat to the desiccant. These repairs were executed prior to operation. After the shakedown of this system, it was also noted that some repairs were needed to the thermocouples and the heating elements. An even heating distribution was needed to ensure the desiccant near the heating source was not overheated while other areas had not reached temperatures ensuring they had been fully dried. Historically, regeneration or drying of the desiccant could take between six and twenty four hours. During shakedown, the desiccant took approximately eight hours to be regenerated. Since this could take a day away from testing if not properly anticipated, the humidity level during supersonic operation must be monitored to anticipate when regeneration will be needed.

7.5 TEN-STAGE TUNNEL COMPRESSOR

During refurbishment, the compressor had been overhauled and the blades were repaired as needed. This work allowed the compressor to be reliably run with the next overhaul scheduled after 2,000 hours of operation. During operation, some movement of the vane settings was noticed on a few of the vane configurations. This was particularly noted in the first and second vane stages after the guide vanes. Although the movement was minimal and the control system was maintaining approximately the correct settings, this should be something that is monitored so that unnecessary loading and fatigue is not acting on the vanes. This could result in breakage and require repairing a significant portion of the compressor.

7.6 3500 & 5000 HP MOTORS

The motors are critical to the operation of the TGF. They are coupled by an approximate 3.5:1 ratio gearbox to drive the ten-stage compressor at a final 3600 RPM. Problems with the systems that support the motors, such as the liquid rheostat can cause major delays in experimentation. This was experienced during shakedown and the notes of which are in section 8.1.3. There are also challenges to the operation of the motors, as described in the next two sections.

7.6.1 SYNCHRONIZATION

Synchronizing the motors gives a minimum Mach of approximately 0.3. Historically, the second motor was not always present and the system can be run on just the 3500hp motor. The motors were not operated in this fashion during shakedown since the use of this configuration, which would give a Mach less than 0.3, is not expected to be a common condition in the TGF. It is expected that if experimentation below Mach 0.3 is needed, it will likely occur in the SARL or VWT, which are designed to operate in this range. The use of the oscilloscope and the automatic synchronizer has improved the efficiency of the synchronizing process, though it is a unique system that must be carefully implemented, otherwise the automatic synchronizer has been known to take a significant amount of time to reach synchronization.

7.6.2 CURRENT BALANCING

The balancing of current between the motors becomes critical at high total pressures where power is near the maximum and during de-synchronization such as during running model changes. At high pressures, the current tends to fluctuate and the balance must be closely monitored near these conditions. During running model changes, if not enough current is removed from the 3500 hp, after the 5000hp is tripped, the system may overload and the 3500hp breaker may trip. This will cause significant down time to reset the system, allow the compressor rotation to stop, restart the system and go through another warm-up cycle.

8.0 SUMMARY AND CONCLUSIONS

The shakedown of the TGF not only allowed the operation team to learn how to effectively operate the tunnel and establish and control the flow but also provided the time to find and fix problems of the tunnel and its subsystems. Although many of the settings differed from historical records, this shows the versatility of the tunnel and that a control calibration alone will not provide all the data necessary to fully understand how to operate the facility. It will also require detailed record keeping from future tests and months if not years of experience. That being said, the control calibration has been a critical step in the learning process of how to operate and maintain the TGF. It also have been a critical step in bringing a wind tunnel that was effectively decommissioned, though not officially given that status, back into operational status. This act of re-commissioning a wind tunnel facility, from all known accounts, is the first time that an effort such as this has been successfully accomplished.

8.1 LESSONS LEARNED

There were also several lessons learned during the shakedown of the TGF. The major lessons are given below. The purpose of these lessons is to improve operations in future experiments and to note issues with the system that could present a problem in the future.

8.1.1 THE CALIBRATION

During control calibration, it was noted that total pressure setting seemed to have an affect on the calculated Mach number. After operation of the shakedown during the flow calibration run, it was discovered that the total and static pressure transducer calibrations were incorrectly entered into the system. The calibration uses polynomial curve fits of the set pressure verses actual readout. On the calibration for the shakedown, the axes were switched. This introduced error in the tunnel data and therefore to the Mach number. It was noted especially on the last day of shakedown that there was a more significant error in Mach at low pressures than at high pressures. Attempts were made to correct this data through re-inverting the original polynomial constants for the DAQ static and total pressures. A new calibration of the system was also done after the shakedown test and the values of it were applied to the shakedown data. Both methods of correcting the data did not lead to Mach numbers that were independent of pressure nor were they any more accurate to the historical, expected Mach numbers.

The closest method to correcting the data was by adding in a bias to static and total pressure. During calibration after the shakedown, a bias of 3psf for the total pressure and a bias of 2psf for the static pressure was noted. Applying these biases gave values that were more consistent with the data taken during the shakedown, as shown in Table 8. If the estimation of bias is correct, it should result in data that matches the Mach measured online. Though, these biases still produce errors that are larger than ±0.05 Mach measured.

Due to the large error of the previous biases, a more refined method of calculating bias was undertaken. Comparing the DAQ static pressure to the wall static measured at tap #12 on the tunnel monitoring system, which is just upstream of the test section window and near the location where static pressure is measured for the DAQ, for all on-condition data from 14 Dec (Mach 3) gave an average bias of 6.97psf and a standard deviation of 15.51psf. The variation of the static pressure bias was significant, as shown in the high standard deviation for the static pressure, though it did not seem to be dependent on the total pressure setting. Therefore a numerical study for accuracy of the Mach number when the biases of 2psf for total pressure and 7psf for static pressure was undertaken. These results, shown also in Table 8, compared much better to the measurements taken during shakedown, giving Mach ±0.03 to what was measured online. Since we were trying to approach Mach ±0.05, this was deemed as an acceptable correction. This correction is not applied to any of the data presented in this report except for in the run log, Appendix C. To correct data, therefore, the DAQ total pressure needs 2psf added and the static pressure needs 7psf subtracted. When applied to Equation 1 from Section 5.1, this will increase the Mach, closer to expected values.

Table 8. Bias error correction of Supersonic data

Mach	Po assumed (psf)	Mach measured online	Mach uncertainty P0-2, PS+3	Mach uncertainty P0-2, PS+7	Dew Pt
1.50	700	1.4490	1.4872	1.4730	5.5
1.90	700	1.8218	1.8800	1.8562	-2.2
2.30	700	2.2398	2.2648	2.2229	-22.6
3.00	700	2.7758	2.9012	2.7916	-20.4
3.00	1000	2.8517	2.9293	2.8473	-18.2
3.00	1500	2.9091	2.9520	2.8942	-17.4
3.00	2000	2.9330	2.9637	2.9191	-17.1
3.00	2500	2.9468	2.9708	2.9345	-16.9

8.1.2 PLANNING

Because many of the problems with achieving control of the wind tunnel flow was not anticipated, much of the planning was not done well in advance as it should have been. This led to some inefficient runs and some tunnel settings that were run that were not effective. Much of this could have been avoided if planning had been done more effectively, particularly with the use of a larger more experienced team, which may have included the previous TGF operators to bring additional insight, direction and advice about the TGF idiosyncrasies. An alternative solution would have been to fully analyze the data and stop testing until a new plan or approach was created if the previous run had significant problems or data that showed a drastic change from previous runs or expected values rather than making rushed decisions in order to stay on schedule.

8.1.3 FULL INVESTIGATION OF PROBLEMS AT THE BEGINNING

When a problem that shuts down operation of the facility is discovered, the possible sources of it need to be fully investigated. This was seen with the problem of the inability to get the 3500Hp motor to turn over on several occasions. It was assumed, initially, that the problem was from low levels of soda ash. When a significant amount of soda ash was added without positive results, a broader investigation showed that it was due to low water levels in the rheostat due to a leaking seal. If the problem had been more fully investigated at the beginning rather than attempting to solve it with the easier solution, at least two days of operational time and possibly some of the eight days of repair time could have been saved. The discovery of this solution was complicated by the lack of the correct equipment to determine if enough soda ash was present in the water. Having the correct equipment costs money and doing a complete investigation can cause significant delays, especially in cases where a problem is not found immediately or the problem is only intermittent. These delays, though, should be considered as minor costs in comparison to the costs associated with the risk of compounded damage from things not being repaired within a reasonable amount of time.

8.1.4 POWER

The major event associated with the extended operation time of tunnel system was power limitations. This was not well anticipated and therefore delayed completion of testing. Power resources are limited on first shift due to the base power grid and the operation of other facilities, such as SARL and the Mach 5 Plasma tunnel which are in competition for available power. These power limitations delayed the initiation of testing once the facility was ready in order to give power and testing priority to SARL since it has a shorter operation window. Because the tunnel had not been run in several years, it was not fully understood how much power the system would require to operate and therefore it was still seen as feasible and desirable to test on first shift. There was also an initial hesitancy of testing on third shift, which would not have these power restrictions, due to the lack of support during the learning phase of operations and if problems were encountered.

8.1.5 THE SCHLIEREN

The Schlieren system was a new installation of the previous system with significant upgrades to the light source, the imaging camera and the optics as well as refurbishment of the mirror surfaces. The system had not been shaken down separately and had not been installed on the final mounting system during shakedown of the TGF. Problems from inexperience of aligning the system and optics and placement of the knife edge created overexposure, brightness gradients across images, blurriness and high noise levels in the images. The source was on a tripod until the final mount was built and installed. The tripod was moved for each nozzle block change and possibly moved due to vibrations in the floor. Therefore daily alignment of the system was needed. This was later fixed by the installation of the final source mounting.

Inexperience also led to problems of the brightness of the image, which appears to cycle during operation. The cycling was partially from unfamiliarity with the auto adjustment of the camera and its interaction with the imaging software. It was later found to be partially caused by the ambient light, particularly from the room lighting and the lack of optical filters. In the future, filters need to be utilized and an enclosure of the camera and optics system needs to be created to limit ambient light from entering the system.

A problem with local temperature variations outside of the tunnel but along the integration path was found to have significant impact of the Schlieren images. The control room and the test section area are on two different temperature control systems. This temperature difference alone creates some noise in the Schlieren. The control room also has local temperature discontinuities since the cooled air is vented into the room from under the raised floor. This floor had panels missing within the Schlieren integration path because the temporary Schlieren mounting was larger than the final, so panels were temporarily removed. This created a significant discontinuity and for much of the operation, the air conditioning in the control room was turned off. This was problematic for the operators who sat near the PCs that control the tunnel and which create a significant amount of heat. After the floor panels are returned to the final configuration, turning off the air conditioning should no longer be necessary as long as vented panels are not placed near the Schlieren integration path.

8.1.6 CORRECTIONS TO HOW TGF IS OPERATED

During operations, we noted several problems with our operation sheet/checklist. Some of these problems were identified during operation and made note of where to update the manual. Some things found in the operations checklist and during operations needed to be corrected within the tunnel control, monitoring and DAQ systems. Two such things that changed the tunnel systems included discovering the need to allow each vane stage to be independently operated and the discovery that of the use of one of the three keys on the operations panel during model changes prevented the tunnel from being safely operated. Also, one procedural problem came to light during operation: the tunnel engineer must fully confirm every step has been checked off and is complete on the operational checklist. One time when this was not done correctly, the 3500Hp motor was overpowered during a running model change and the system tripped the breaker. This prematurely ended operations for the day. These are mentioned to be verified in future testing of areas for improvement that have been completed.

8.1.7 PIGGYBACK EXPERIMENTS

An investigation into the boundary layer thickness was piggybacked onto the tunnel shakedown. This created only slight problems, but the potential for conflicts of interest and larger problems became apparent. All piggyback efforts on an existing test must be aware of the operational goals and the test plan. The piggyback must be created well in advance to minimize impact to the host test. If the impact of the piggyback cannot be minimized, it should be considered for entry as a separate experiment, especially if there is little benefit to the original entry. In this experiment, the piggyback only created slight delays during testing but the installation of the piggyback entry was not well planned and therefore caused problems with installation and operation of the device.

9.0 REFERENCES

1. White, Howard L. Trisonic Gasdynamic Facility User Manual. DTIC Tech Memo # TM 73-82 FXM, June 1973

2. Heppe, R. Richard. “Investigation of a Variable Geometry Supersonic Diffuser”, Cal Tech Thesis 1947

APPENDIX A

Facility Description

The Trisonic Gasdynamics Facility, Figure A-1, is a closed loop, variable density, continuous flow wind tunnel operated by the Air Vehicles Directorate of the Air Force Research Laboratory, Wright-Patterson Air Force Base. The TGF has a two foot by two foot (2' x 2') test section for subsonic conditions up to Mach 0.85 and supersonic experiments. Although not currently operational, a 15 inch by 15 inch test section with slotted walls is used for transonic experiments up to Mach 1.0. The supersonic nozzles provide distinct Mach numbers: 1.5, 1.9, 2.3 and 3.0. The tunnel's operational envelope depends on Mach. The historical operational envelopes for subsonic and supersonic conditions are given in Figure A-2 and Figure A-3 respectively. The tunnel has a minimum total pressure of 500psf for all conditions.

The model can be accessed during operation through the 28 inch diameter Schlieren quality side windows, which can be opened after bypassing the flow through a bypass air line and equalizing the tunnel pressure to atmosphere. This process can take approximately 15 minutes but saves an additional 20 minutes from stopping the drive train system, which consists of a 3500hp induction motor synchronized to a 5000hp synchronous motor that drive a ten staged, 4.26:1 compression ratio Allis Chalmers VA 1310 axial flow compressor with variable angled blades. At maximum tunnel conditions, this system can draw up to 7MW.

The temperature is controlled by two heat exchanger coils located in the each of the two 90° turns of the tunnel between the compressor and test section. The typical stagnation temperature is 100°F. This is a closed loop cooling system that is connected to a pump house exterior to the TGF building which exchanges the heat from the tunnel to water in a Carrier cooling tower. To ensure high quality flow uniformity and reduce turbulence, a honeycomb and screen arrangement is located just after the cooling coils in the 8 foot by 8 foot stagnation section. As well as temperature control, the TGF has a molecular sieve dryer system to reduce humidity to a dew point as low as -35°F.

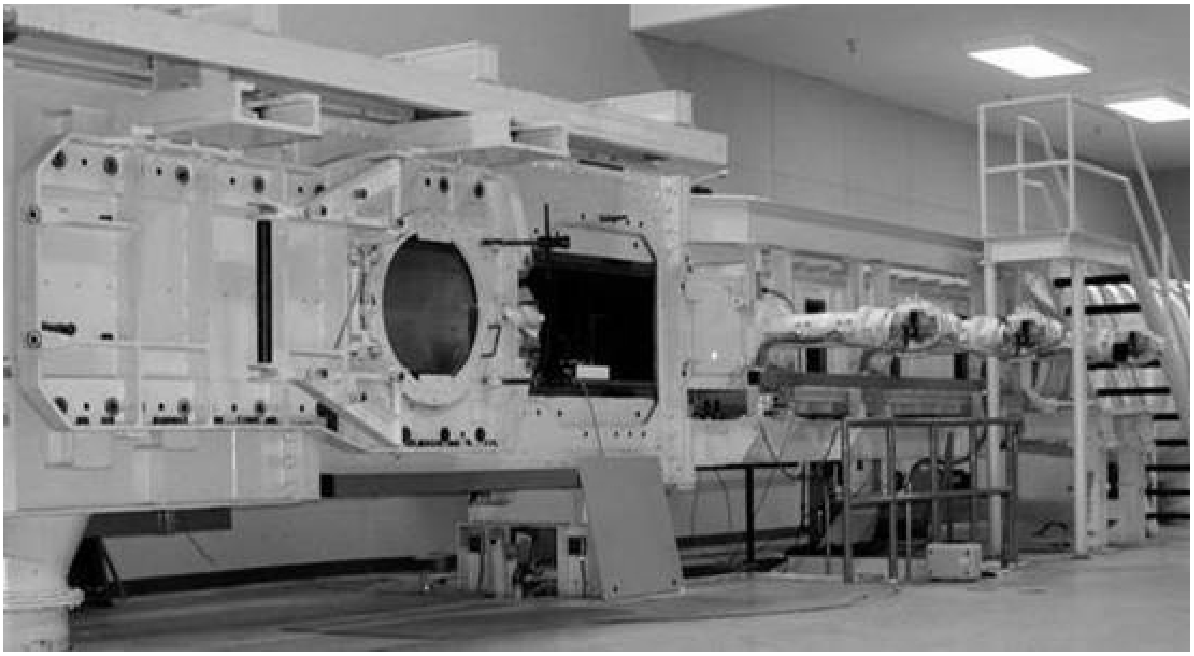


Figure A-1. TGF with Side Wall Open for Nozzle Change

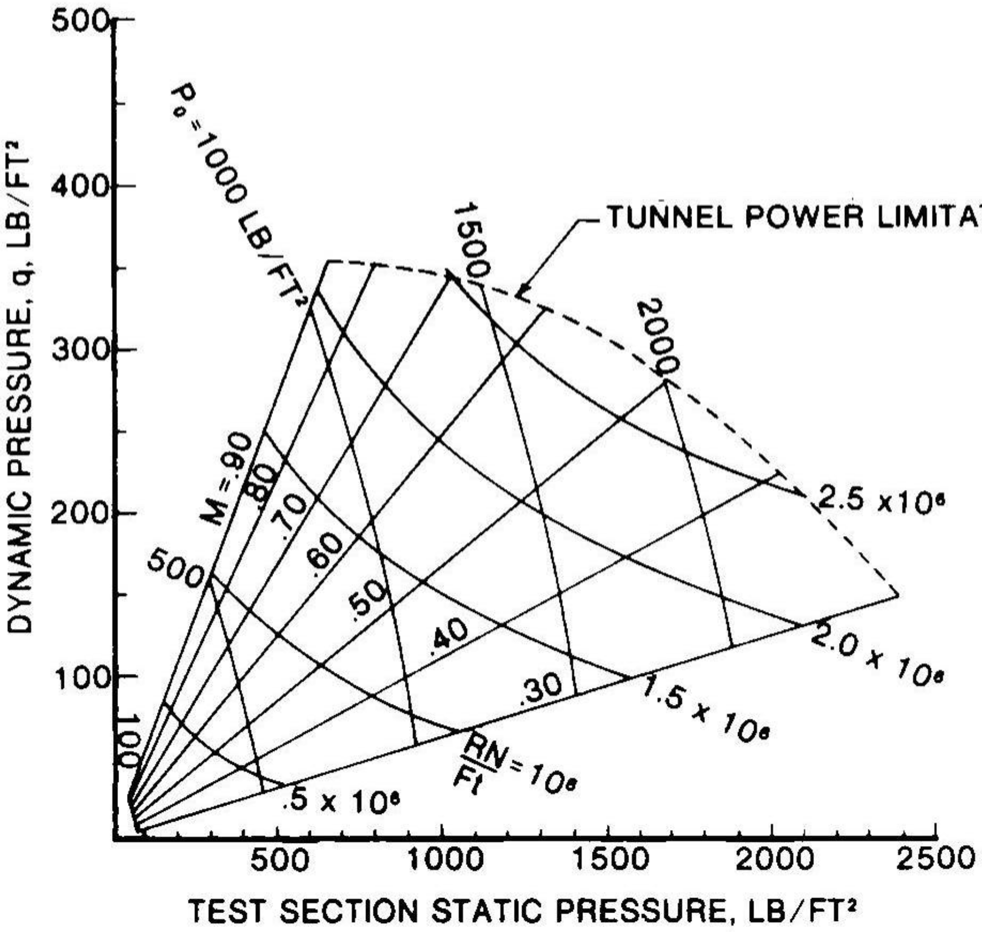


Figure A-2. TGF Subsonic Operational Envelope

NOTE: THE TEST SECTION EMPLOYS FIXED NOZZLE BLOCKS AND OPERATES ONLY THE DESCRETE MACH NUMBERS INDICATED

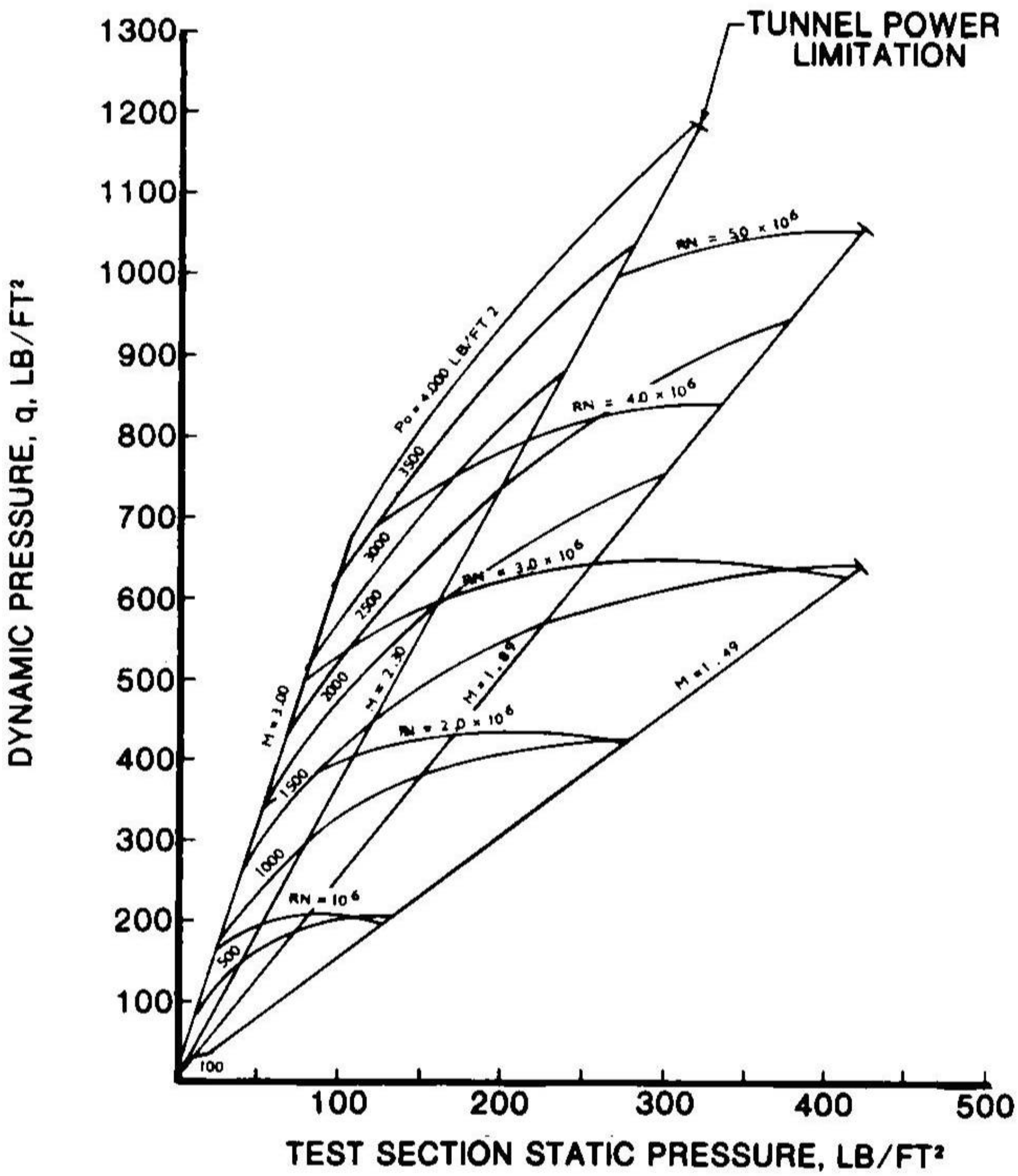


Figure A-3. TGF Supersonic Operational Envelope

APPENDIX B

Model & Test Set Up Drawings

Due to the simple nature of the model of the shakedown and control calibration and the fact that a historical model was used, no original model drawings could be located. Figure B-1 is a recreation of the wedge model based on measurements taken from it and notes the assumption about the material used to make it. This is later used in the stress analysis in Appendix D.

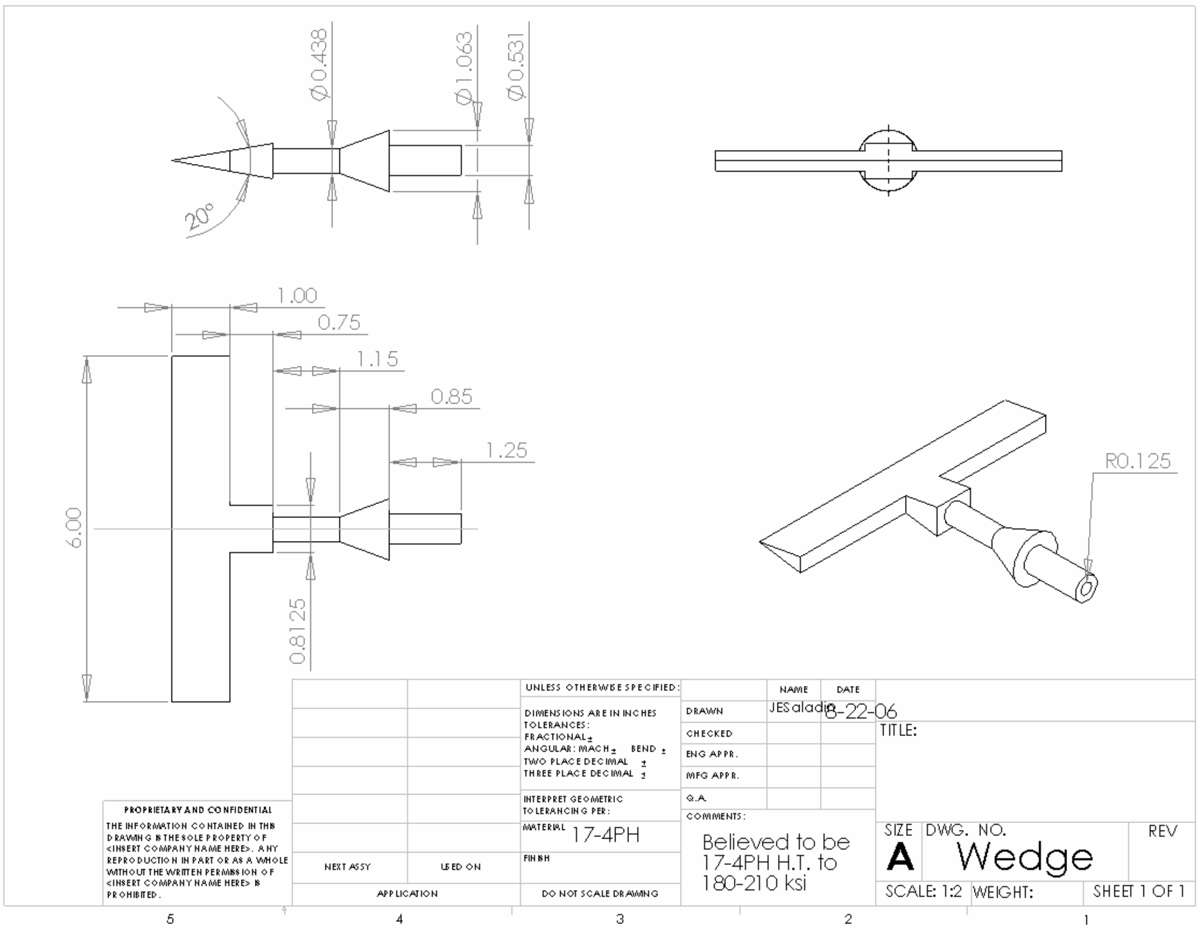


Figure B-1. Re-created drawing of wedge model used in shakedown

APPENDIX C

Run Log

The following is a log of the shakedown operations. Problems with the system, general data points taken, and some of the data are recorded to show facility problems as well as how the data and ability to operate the facility directed testing. All runs from the shakedown were conducted in 2005.

Day 1 – Aug 31

While awaiting completion of SARL testing so power would be available for TGF, had a rainy day so SARL could not run. Since there was enough power to begin shakedown, ran the TGF for the first time. This initial testing investigated three factors: the impact of bypass valve on low Mach number, the power required to operate, and what angle settings are necessary to achieve each subsonic Mach number. This proved the tunnel system could be run on the new control system, which revealed errors in the PLC logic and also showed areas where operation flexibility improvements could be made. Such implemented improvements included allowing for numerical inputs for the vane angle settings.

Day 2 – Oct 4

After SARL was fully completed, ran more subsonic control calibration settings. Had problems with start-up of 3500Hp motor, which is discussed in detail in Lessons Learned, Section 8.1.3. Once tunnel was running, attempted to run tunnel at 90% power consumption-condition to check for motor surging and temperature fluctuations. Using settings expected to give high power use, attained only 60% power usage (based on maximum power of 7MW). These settings, though, did run the tunnel above atmospheric pressure for first time. Noted an error of data from the tunnel monitoring system settings: the accuracy of all measurements changed depending on the units in which pressure was being recorded. When measured pressures was in psf, the system rounded all measured values to the nearest integer, including vane angle and wall settings.

Day 3 – Oct 5

Thus far in testing, tunnel had not been operated above Mach 0.7. Ran in attempts to attain Mach 0.8, but did not achieve goal. Team called in compressor expert Doug Rabe from AFRL/PR for consultation on the compressor profile. Also attempted to do a running model change, but realized the procedures needed to be changed slightly for success and safety.

Day 4 – Oct 11

Based on input from Doug Rabe and Jason Parson of AFRL/PR, achieved Mach 0.75 flow. By changing stage angles independent to each other, could get same Mach number with various vane settings. This had some but not a significant impact on power consumption, mainly due to low power required to operate at a total pressure of 500psf. Noted to increase the pressure was taking minutes instead of the expected seconds. This would be resolved later by adding compressor capability.

Day 5 – Oct 13

Took best setting from previous run and attempted to get Mach 0.8. Based on input from Larry Rieker, a previous operator of TGF, moved diffuser walls from outer wall one-half inch towards the center from open, the historical setting, to completely open. Together with changing the guide vane angle, this achieved Mach 0.8 flow. In attempt to go higher Mach number, ran historical vane settings, but without success.

After Doug Rabe and Jason Parson looked at data collected to date on 17 Oct, they noted a significant drop in pressure in stage 10 and 9 that would be attempted to be reduced by changing the vane settings in the various stages during the next run. It was expected that this would also allow for higher speed flows.

Day 6 – Oct 20

Adjusting the vanes according to Doug & Jason's suggestions and achieved Mach 0.87 flow. Achieved a good pressure profile in the compressor, which became an example for running the tunnel.

Day 7 – Oct 26

Had difficulty getting the motors to turn over. Thought it was still due to low levels of soda ash, a water additive in the motor's rheostat. Prior to running, also had power conflict with Mach 5 tunnel, but due to need for full shakedown of TGF, preference given to TGF. After waiting on SARL, this was the second indicator that the tunnel needed to be run on third shift. Duplicated some runs from previous data and attempted to create "finalized" vane schedules for the various Mach numbers. Completed subsonic shakedown and next few days were in preparation to run the Mach 1.5 nozzle block.

On Nov 2, attempted to run but had difficulties again. Added a significant amount of soda ash and finally got the system to run, but had to stop before motors could synchronized in order to defer to running SARL. On Nov 3, regenerated the mole dryer to have low humidity for supersonic operation.

Day 8 – Nov 7

Had no problems on start up, rather had problems with over heating vacuum pumps. This would continue intermittently throughout shakedown testing. Were not successful on attempts to achieve on-condition flow. Achieved up to Mach 0.86 flow, even after adjusting vanes from historical settings.

Day 9 – Nov 8

Attempted, without success, to get on-condition by adjusting the second throat, by-pass and vane angles. Noted a lower than normal RPM of the 3500 Hp motor during warm-up, which indicated a need for more water to balance out the significant amount of soda ash added on Nov 2nd.

Day 10 – Nov 15

Due to problems with start-up, turned compressor over by hand. Noted amperage of 3500Hp was jumping throughout operations. Further investigation after operation located a missing water seal which was fixed before the next day of testing. Reached Mach 1.46, without calibration correction, during operations through optimizing the compressor profile. The calibration is discussed more in Section 8.1.1. The corrected value of the maximum Mach for this run is 1.479. The recovery pressure drop, which is correlated to a recovery shock, is very far down the test section by the model support crescent. Investigated effect of wall settings, which led to a no-start (supersonic shock was not swallowed through test section) when attempts to establish flow by closing the bypass.

Day 11 – Nov 28

At start up, still had problems getting turn-over. Added soda ash & finally turned over by hand. Ran attempting to move recovery shock more downstream without success. Decided to move on with Mach 1.9. Post note: had been changing controls off-condition with bypass open and then attempting to re-establish flow by closing bypass. May be more likely to move the shock if change the wall settings after establishing flow.

Day 12 – Nov 30

Noted shaking of model during initial runs, especially when come on and off-condition. Achieved Mach 1.825 flow (uncorrected value). The corrected Mach number is 1.865.

On Dec 1, ran tunnel to finish Mach 1.9 control calibration but had visitors who needed to view the tunnel interior, so attempted to do a running model change since procedure had been corrected since previous attempt. Operator error caused over current of 3500hp and operation to end for the day.

Day 13 – Dec 2

When ran, changed vane and walls to get reliable flow establishment. Noted that sometimes it took several seconds for flow to attach to model and sometimes never reached model but stayed as a normal shock just upstream of model. Began to work with the temperature controls, adjusting the amount that the cooling valve was open to control temperature to 100°F. Could better control temperature to 70°F, but could not maintain to 100°F.

During Dec 3rd through 7th, changed to Mach 2.3 blocks and regenerated mole dryer. Also installed pitot probe for boundary layer thickness research. This ran in conjunction with the shakedown & subsonic flow calibration.

Day 14 – Dec 8

Continued to have significant difficulties with the vacuum pump cooling. Attained Mach 2.25 (uncorrected; corrected value is 2.322). Believed, not being aware of the incorrect calibration, that high humidity in the tunnel was a factor in not achieving Mach of 2.30, but noted that had been able to get on-condition with well developed shocks. Therefore saw operation as successful and decided to proceed to Mach 3.0 nozzle block.

Day 15 – Dec 12

Worked with bypass to determine if needed for operations. Achieved Mach 2.78 at 700psf total pressure (corrected to Mach 2.970). At end of day's operation with reliable settings, increased pressure and saw corresponding increase in Mach number. Achieved Mach 2.91 at 1500psf, which is corrected to Mach 3.016.

Day 16 – Dec 14

Ran tunnel health monitoring system and finished Mach 3 run. Noted that the vane angles tend to move slightly around the set point during running. This was also the first day runs were made while keeping the bypass closed between control settings such as vane angle, pressure, and wall settings. Ran almost the full range of total pressure while on-condition. Found could maintain established flow at 500psf. When increased pressure to 700psf, found it was easier to establish flow. Achieved Mach 2.94 (corrected to 3.015) at almost 2500psf total pressure.

Completed shakedown and control calibration with successful establishment of supersonic flow for all nozzles and operation of the subsonic at a full range of Mach numbers.

APPENDIX D

Test Data

Data from the DAQ and Tunnel Monitoring System were used in conjunction for the shakedown and control calibration. The tunnel monitoring system records numerous parameters, which are listed in Table D-1 for reference.

Table D-1. Measured Tunnel Parameters List

Parameter	Description
PCIT	Compressor Inlet Total Pressure
PCIS	Compressor Inlet Static Pressure
PGV	Guide Vane Static Pressure
PCR1	Compressor Rotor # 1 Static Pressure
PCS1	Compressor Stator # 1 Static Pressure
PCR2	Compressor Rotor # 2 Static Pressure
PCS2	Compressor Stator # 2 Static Pressure
PCR3	Compressor Rotor # 3 Static Pressure
PCS3	Compressor Stator # 3 Static Pressure
PCR4	Compressor Rotor # 4 Static Pressure
PCS4	Compressor Stator # 4 Static Pressure
PCR5	Compressor Rotor # 5 Static Pressure
PCS5	Compressor Stator # 5 Static Pressure
PCR6	Compressor Rotor # 6 Static Pressure
PCS6	Compressor Stator # 6 Static Pressure
PCR7	Compressor Rotor # 7 Static Pressure
PCS7	Compressor Stator # 7 Static Pressure
PCR8	Compressor Rotor # 8 Static Pressure
PCS8	Compressor Stator # 8 Static Pressure
PCR9	Compressor Rotor # 9 Static Pressure
PCS9	Compressor Stator # 9 Static Pressure
PCR10	Compressor Rotor # 10 Static Pressure
PCS10	Compressor Stator # 10 Static Pressure
PCDIS	Compressor Discharge Pressure
PBC1	Pressure before first cooling coils
PBC2	Pressure between cooling coils
PMDI	Mole Dryer Inlet Pressure
PMDO	Mole Dryer Outlet Pressure
PBPVI	Bypass Valve Inlet Pressure
PBPVO	Bypass Valve Outlet Pressure
PVAC	Vacuum System Pressure
PHI	S Static Pressure before Honeycomb
PNS2	S Nozzle Static Pressure Tap # 2
PNS4	S Nozzle Static Pressure Tap # 4
PNS6	S Nozzle Static Pressure Tap # 6
PNS8	S Nozzle Static Pressure Tap # 8
PNS10	S Nozzle Static Pressure Tap # 10
PNS12	S Nozzle Static Pressure Tap # 12

Parameter	Description
PWAL	Wall Static Pressure Tap
PDS1	Diffuser Static Pressure Tap # 1
PDS2	Diffuser Static Pressure Tap # 2
PDS3	Diffuser Static Pressure Tap # 3
PDS4	Diffuser Static Pressure Tap # 4
PDS5	Diffuser Static Pressure Tap # 5
PDS6	Diffuser Static Pressure Tap # 6
PDS7	Diffuser Static Pressure Tap # 7
PDS8	Diffuser Static Pressure Tap # 8
PDS9	Diffuser Static Pressure Tap # 9
PDS10	Diffuser Static Pressure Tap # 10
PDS11	Diffuser Static Pressure Tap # 11
PDS12	Diffuser Static Pressure Tap # 12
PDS13	Diffuser Static Pressure Tap # 13
PDS14	Diffuser Static Pressure Tap # 14
PDS15	Diffuser Static Pressure Tap # 15
PDS16	Diffuser Static Pressure Tap # 16
PDS17	Diffuser Static Pressure Tap # 17
PDS18	Diffuser Static Pressure Tap # 18
PDS19	Diffuser Static Pressure Tap # 19
PDS20	Diffuser Static Pressure Tap # 20
PDS21	Diffuser Static Pressure Tap # 21
PDS22	Diffuser Static Pressure Tap # 22
PDS23	Diffuser Static Pressure Tap # 23
PDS24	Diffuser Static Pressure Tap # 24
TCI1	Compressor Inlet Temp #1
TCI2	Compressor Inlet Temp #2
TCO1	Compressor Outlet Temp #1
TCO2	Compressor Outlet Temp #2
TCD	Compressor Diffuser Temp
VAGV	Guide Vane Angle
VAS1	Compressor Stator # 1 Vane Angle
VAS2	Compressor Stator # 2 Vane Angle
VAS3	Compressor Stator # 3 Vane Angle
VAS4	Compressor Stator # 4 Vane Angle
VAS5	Compressor Stator # 5 Vane Angle
VAS6	Compressor Stator # 6 Vane Angle
VAS7	Compressor Stator # 7 Vane Angle
VAS8	Compressor Stator # 8 Vane Angle
VAS9	Compressor Stator # 9 Vane Angle
VAS10	Compressor Stator # 10 Vane Angle
TCLIN	Temp Before First Cooling Coil - North
TCLIS	Temp Before First Cooling Coil - South
TCLBN	Temp Between Cooling Coils - North
TCLBS	Temp Between Cooling Coils - South
TON	Stagnation Temp - North
TOS	Stagnation Temp - South

Parameter	Description
WPOS1	Wall position pot voltage -#1
WPOS2	Wall position pot #2 voltage
WPOS3	Wall position pot #3 voltage
WPOS4	Wall position pot #4 voltage
WPOS5	Wall position pot #5 voltage
WPOS6	Wall position pot #6 voltage
DP1	Dew Point 1
WINL1	Wall drive #1 inner limit
WOUTL1	Wall drive #1 outer limit
WINL2	Wall drive #2 inner limit
WOUTL2	Wall drive #2 outer limit
WINL3	Wall drive #3 inner limit
WOUTL3	Wall drive #3 outer limit
WINL4	Wall drive #4 inner limit
WOUTL4	Wall drive #4 outer limit
WINL5	Wall drive #5 inner limit
WOUTL5	Wall drive #5 outer limit
WINL6	Wall drive #6 inner limit
WOUTL6	Wall drive #6 outer limit

The following tables and charts record the data points taken on every day of the shakedown testing and give an example of the data available from the shakedown. While the data for the first day of testing is recorded in this document, the rest of the data is on record in the wind tunnel facility files for future use in CD and hardcopy formats.

Table D-2. Aug 31 (First Run) Run Schedule with outputs and notes (duplicate of Table 1)

Wright Patterson Tri-Sonic Gas Dynamics Facility August 31, 2005

Subsonic Calibration - Shakedown of Facility

		Independent Variables			Response Variables					Comments	Voltage 2400	Voltage 6900	
Data Point	**Test Set Point**	**Pressure [psf]**	**Set Mach Number**	**Bypass**	**Vane Angle**	**Current on 3500 [Amps]**	**Current on 5000 [Amps]**	**Actual Mach**	**Actual Mach (II)**	**Start Run Prep 0900 Sync 1019 Shutdown 1124**	**Power 3500 [kW]**	**Power 5000 [kW]**	**Total Power [MW]**
2	1	500	0.3	Open	-20	400	40	0.29	0.3	Walls Open at TSPt 1 ONLY	960	276	1.24
3		500	0.3	Open	-20	387	39	0.27	0.27	Walls: 1&2, 3&4, 5&6	929	269	1.20
4	2	500	0.3	1/2	-20	386	40	0.31	0.31	14.49 & 14.52	926	276	1.20
5	3	500	0.3	Closed	-20	385	40	0.34	0.33	14.38 & 14.36	924	276	1.20
6	6	500	0.4	Closed	-16.6	382	53	0.4	0.4	14.55 & 14.56	917	366	1.28
7	9	500	0.5	Closed	-12.2	392	75	0.5	0.49		941	518	1.46
8	12	500	0.6	Closed	-9.4	392	95	0.6	0.6		941	656	1.60
9	15	500	0.7	Closed	-4.5	389	108	0.7	0.69		934	745	1.68
	18	500	0.8	Closed						Vane @ +5: No change			
					-20	380	100		0.33	So unload & go to next.	912	690	1.60
10	21	1000	0.3	Closed	-20	379	156	0.33	0.33		910	1076	1.99
11	24	1000	0.4	Closed	-16.6	385	186	0.39	0.39		924	1283	2.21
12	27	1000	0.5	Closed	-11.6	389	235	0.5	0.5		934	1622	2.56
13	30	1000	0.6	Closed	-8.8	380	274	0.6	0.6		912	1891	2.80
14	33	1000	0.7	Closed	-3.6	381	294	0.7	0.69		914	2029	2.94
15	36	1500	0.3	Closed	-20	389	271	0.32	0.33		934	1870	2.80
16	39	1500	0.4	Closed	-15.6	389	337	0.41	0.41		934	2325	3.26
17	42	1500	0.5	Closed	-11.8	450	367	0.5	0.49		1080	2532	3.61

Table D-3a. Aug 31 (First Run) Data from DAQ and Tunnel Monitoring System

ASCII TEXT
Timestamp: 2005/08/31, 10:40.24
Data Rate: 0.1000 sec/pt
Channels: 11

		Timestamp (sec)	191	156	201	189	203	122	190	202	100003	113				
DAQ		0	P0 (psi)	P0 man (psia)	P0 psf (psf)	P02 (psi)	P02 psf (psf)	P1Ch1 (psid)	PS (psi)	PS psf (psf)	System Time (sec)	T0 (V)	Mach	Mach	Re	Re
		()														
TP	N/A	N/A	N/A	N/A	[P0]*144	N/A	[P02]*144	N/A	N/A	[PS]*144	N/A	N/A	Eq. 1 (P0)	Eq. 1 (P02)	Eq. 2 (P0)	Eq. 2 (P02)
0	8/31/2005 10:02	VOID	14.2739	0	2055.4462	14.2763	2055.7806	14.4061	14.0675	2025.7212	982.775	527.4657	0.144	0.145	906,504	911,562
1	8/31/2005 10:22	500 psf, 0.3, open	3.5575	0	512.2794	3.5587	512.4482	3.6896	3.3468	481.9421	2225.075	530.3197	0.297	0.297	1,866,929	1,872,004
2	8/31/2005 10:32	500 psf, 0.3, open	3.5447	0	510.4407	3.5468	510.7406	3.6925	3.3413	481.1484	2804.8749	532.1227	0.292	0.293	1,839,771	1,848,969
3	8/31/2005 10:35	500 psf, 0.3, 1/2	3.5583	0	512.3952	3.5584	512.406	3.678	3.3299	479.5042	2967.6749	532.5735	0.309	0.309	1,951,118	1,951,431
4	8/31/2005 10:36	500 psf, 0.3, closed	3.5706	0	514.1614	3.5721	514.386	3.6512	3.3076	476.298	3023.5749	532.7198	0.332	0.333	2,096,872	2,102,916
5	8/31/2005 10:40	500 psf, 0.4, closed	3.5285	0	508.0994	3.5311	508.4725	0	3.1662	455.9263	41.925	533.0869	0.396	0.398	2,502,119	2,510,713
6	8/31/2005 10:43	500 psf, 0.5, closed	3.5248	0	507.5719	3.5338	508.8653	0	2.9778	428.8424	209.875	533.8574	0.497	0.500	3,136,593	3,160,764
7	8/31/2005 10:45	500 psf, 0.6, closed	3.5191	0	506.8081	3.5287	508.1259	2.9493	2.7541	396.7874	348.375	534.4459	0.602	0.605	3,802,474	3,823,312
8	8/31/2005 10:46	500 psf, 0.6, closed	3.5483	0	510.948	3.5505	511.2691	3.1179	2.781	400.4698	386.375	534.6314	0.600	0.601	3,794,256	3,799,318
9	8/31/2005 10:47	500 psf, 0.7, closed	3.563	0	513.0786	3.5663	513.5448	2.9271	2.5946	373.6185	462.175	535.0239	0.689	0.690	4,354,076	4,360,592
10	8/31/2005 11:02	1000 psf, 0.3, closed	6.9486	0	1000.5915	6.9509	1000.9279	6.7796	6.4457	928.1756	1374.125	539.4486	0.329	0.330	2,090,918	2,095,641
11	8/31/2005 11:04	1000 psf, 0.4, closed	6.9314	0	998.1222	6.934	998.4925	6.5649	6.2264	896.5981	1484.025	540.4665	0.394	0.395	2,506,621	2,511,018
12	8/31/2005 11:05	1000 psf, 0.5, closed	6.9531	0	1001.2461	6.96	1002.24	6.1812	5.85	842.3963	1538.725	541.6057	0.503	0.504	3,199,371	3,208,775
13	8/31/2005 11:07	1000 psf, 0.6, closed	6.9154	0	995.8154	6.9272	997.5211	5.7462	5.4067	778.5432	1655.175	543.1379	0.604	0.606	3,844,653	3,858,473
14	8/31/2005 11:08	1000 psf, 0.7, closed	6.9195	0	996.4143	6.912	995.329	5.3446	5.0145	722.0817	1730.375	543.5612	0.694	0.693	4,423,521	4,415,681
15	8/31/2005 11:15	1500 psf, 0.3, closed	10.1761	0	1465.3524	10.1692	1464.3711	9.7935	9.4535	1361.3046	2109.075	544.416	0.326	0.325	2,079,602	2,070,024
16	8/31/2005 11:16	1500 psf, 0.4, closed	10.347	0	1489.9588	10.3543	1491.0152	9.5712	9.2336	1329.6325	2195.975	544.9426	0.407	0.408	2,594,229	2,602,424
17	8/31/2005 11:18	1500 psf, 0.5, closed	10.3369	0	1488.5712	10.36	1491.8342	9.0674	8.7567	1260.9648	2336.5249	544.7445	0.493	0.496	3,143,203	3,164,372

DAQ		()	System																								
TP	N/A	N/A	TP	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Pot 6	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Pot 6	WM1IL	WM1OL	WM2IL	WM2OL	WM3IL	WM3OL	WM4IL	WM4OL	WM5IL	WM5OL	WM6IL	WM6OL
0	8/31/2005 10:02	VOID	1	1	1	1	1	1	1	10	-11	0	-8	3	-9	1	0	0	0	1	0	0	0	1	0	0	0
1	8/31/2005 10:22	500 psf, 0.3, open	2	1	1	1	1	1	1	15	15	15	15	15	15	0	1	0	1	0	1	0	1	0	1	0	1
2	8/31/2005 10:32	500 psf, 0.3, open	3	1	1	1	1	1	1	15	15	15	15	15	15	0	1	0	1	0	1	0	1	0	1	0	1
3	8/31/2005 10:35	500 psf, 0.3, 1/2	4	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
4	8/31/2005 10:36	500 psf, 0.3, closed	5	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
5	8/31/2005 10:40	500 psf, 0.4, closed	6	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
6	8/31/2005 10:43	500 psf, 0.5, closed	7	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
7	8/31/2005 10:45	500 psf, 0.6, closed	8	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
8	8/31/2005 10:46	500 psf, 0.6, closed																									
9	8/31/2005 10:47	500 psf, 0.7, closed	9	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
10	8/31/2005 11:02	1000 psf, 0.3, closed	10	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
11	8/31/2005 11:04	1000 psf, 0.4, closed	11	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
12	8/31/2005 11:05	1000 psf, 0.5, closed	12	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
13	8/31/2005 11:07	1000 psf, 0.6, closed	13	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
14	8/31/2005 11:08	1000 psf, 0.7, closed	14	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
15	8/31/2005 11:15	1500 psf, 0.3, closed	15	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
16	8/31/2005 11:16	1500 psf, 0.4, closed	16	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0
17	8/31/2005 11:18	1500 psf, 0.5, closed	17	1	1	1	1	1	1	14	15	14	14	15	15	0	0	0	0	0	0	0	0	0	0	0	0

Table D-3b. Aug 31 (First Run) Data from Tunnel Monitoring System

TP	N/A	N/A	PHI	PNS2	PNS4	PNS6	PNS8	PNS10	PNS12	PWAL	PDS1	PDS2	PDS3	PDS4	PDS5	PDS6	PDS7	PDS8	PDS9	PDS10	PDS11	PDS12	PDS13	PDS14
0	8/31/2005 10:02	VOID	2028	2030	2039	2030	2031	2027	2032	2030	2032	2031	2038	2034	2033	2033	2031	2031	2035	2034	2032	2034	2036	2039
1	8/31/2005 10:22	500 psf, 0.3, open	496	466	480	465	469	511	468	466	466	464	471	479	476	471	472	477	476	495	489	478	479	481
2	8/31/2005 10:32	500 psf, 0.3, open	500	468	483	468	472	511	472	473	469	469	472	482	479	478	477	474	474	496	489	477	479	479
3	8/31/2005 10:35	500 psf, 0.3, 1/2	499	467	477	464	470	512	460	470	466	466	472	476	476	477	472	475	479	496	486	477	473	479
4	8/31/2005 10:36	500 psf, 0.3, closed	503	465	465	462	463	511	466	470	463	466	471	476	476	476	472	471	473	495	483	474	475	479
5	8/31/2005 10:40	500 psf, 0.4, closed	502	449	458	446	451	498	448	454	447	448	450	464	463	458	462	459	461	482	475	462	465	465
6	8/31/2005 10:43	500 psf, 0.5, closed	496	424	427	418	421	465	419	431	419	420	431	441	440	443	440	441	443	460	446	440	438	441
7	8/31/2005 10:45	500 psf, 0.6, closed	502	395	395	388	391	439	385	409	386	390	398	417	419	418	415	418	414	439	431	421	422	422
8	8/31/2005 10:46	500 psf, 0.6, closed																						
9	8/31/2005 10:47	500 psf, 0.7, closed	504	370	377	361	366	420	361	387	358	364	377	395	400	401	402	399	403	422	407	400	403	404
10	8/31/2005 11:02	1000 psf, 0.3, closed	991	917	921	914	919	959	912	922	915	916	924	928	932	928	932	929	932	938	936	933	926	935
11	8/31/2005 11:04	1000 psf, 0.4, closed	991	890	893	884	884	928	884	900	884	888	899	908	910	912	905	909	912	919	917	913	912	914
12	8/31/2005 11:05	1000 psf, 0.5, closed	992	838	836	829	832	874	828	860	829	834	847	863	871	875	872	869	877	881	884	873	872	875
13	8/31/2005 11:07	1000 psf, 0.6, closed	989	783	765	768	774	812	766	808	760	772	790	806	823	821	821	821	822	836	838	823	821	828
14	8/31/2005 11:08	1000 psf, 0.7, closed	984	730	709	711	716	758	705	763	707	723	736	763	786	791	788	785	784	795	790	783	784	786
15	8/31/2005 11:15	1500 psf, 0.3, closed	1466	1365	1375	1360	1364	1403	1356	1379	1360	1363	1366	1382	1388	1389	1389	1385	1386	1394	1398	1387	1390	1390
16	8/31/2005 11:16	1500 psf, 0.4, closed	1483	1324	1330	1315	1320	1359	1314	1345	1316	1323	1328	1345	1356	1361	1356	1355	1361	1370	1374	1362	1356	1364
17	8/31/2005 11:18	1500 psf, 0.5, closed	1485	1261	1258	1247	1251	1296	1245	1284	1246	1255	1272	1289	1307	1311	1299	1308	1312	1319	1325	1305	1309	1306

TP	N/A	N/A	PDS15	PDS16	PDS17	PDS18	PDS19	PDS20	PDS21	PDS22	PDS23	PDS24	DP1	VAGV	VAS1	VAS2	VAS3	VAS4	VAS5	VAS6	VAS7	VAS8	VAS9	VAS10
0	8/31/2005 10:02	VOID	2031	2031	2034	2038	2035	2038	2035	2038	2034	2038	31	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
1	8/31/2005 10:22	500 psf, 0.3, open	473	472	477	481	480	474	486	476	478	608	21	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
2	8/31/2005 10:32	500 psf, 0.3, open	481	470	474	480	476	476	486	479	481	606	21	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
3	8/31/2005 10:35	500 psf, 0.3, 1/2	469	470	476	480	479	470	480	476	480	608	22	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
4	8/31/2005 10:36	500 psf, 0.3, closed	478	469	479	478	469	473	483	476	480	609	21	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
5	8/31/2005 10:40	500 psf, 0.4, closed	469	456	464	465	458	462	468	463	464	599	20	-16	-17	-16	-17	-17	-17	-16	-17	-17	-17	-16
6	8/31/2005 10:43	500 psf, 0.5, closed	431	434	443	443	439	436	447	441	437	577	19	-12	-12	-11	-12	-12	-12	-12	-12	-12	-12	-12
7	8/31/2005 10:45	500 psf, 0.6, closed	423	414	421	422	421	421	425	418	417	568	19	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9
8	8/31/2005 10:46	500 psf, 0.6, closed																						
9	8/31/2005 10:47	500 psf, 0.7, closed	392	395	391	405	402	403	412	396	401	556	19	-4	-4	-4	-4	-4	-4	-4	-4	-5	-4	-4
10	8/31/2005 11:02	1000 psf, 0.3, closed	933	925	929	928	932	933	935	933	932	984	23	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
11	8/31/2005 11:04	1000 psf, 0.4, closed	911	906	913	909	913	914	920	914	913	968	23	-16	-17	-16	-17	-17	-17	-16	-17	-17	-17	-16
12	8/31/2005 11:05	1000 psf, 0.5, closed	877	869	869	876	875	869	883	871	876	937	23	-11	-12	-11	-12	-11	-12	-11	-12	-11	-12	-12
13	8/31/2005 11:07	1000 psf, 0.6, closed	834	818	823	829	828	820	834	826	827	892	22	-8	-9	-8	-9	-9	-9	-9	-9	-9	-9	-9
14	8/31/2005 11:08	1000 psf, 0.7, closed	784	779	787	784	790	788	797	788	787	864	22	-3	-4	-3	-4	-3	-4	-3	-4	-4	-4	-3
15	8/31/2005 11:15	1500 psf, 0.3, closed	1385	1382	1392	1391	1386	1391	1396	1383	1387	1411	28	-19	-20	-19	-20	-20	-20	-19	-20	-20	-20	-20
16	8/31/2005 11:16	1500 psf, 0.4, closed	1353	1354	1352	1363	1357	1362	1363	1360	1360	1388	27	-15	-16	-15	-16	-16	-16	-15	-16	-16	-16	-15
17	8/31/2005 11:18	1500 psf, 0.5, closed	1312	1296	1309	1306	1306	1305	1312	1298	1302	1339	25	-11	-12	-11	-12	-12	-12	-11	-12	-12	-12	-11

Table D-3c. Aug 31 (First Run) Data from Tunnel Monitoring System

TP	N/A	N/A	PCIT	PCIS	PGV	PCR1	PCS1	PCR2	PCS2	PCR3	PCS3	PCR4	PCS4	PCR5	PCS5	PCR6	PCS6	PCR7	PCS7	PCR8	PCS8	PCR9	PCS9	PCR10	PCS10	PCDIS
0	8/31/2005 10:02	VOID	2035	2033	2034	2032	2032	2031	2035	2034	2032	2036	2035	2036	2032	2032	2034	2033	2035	2028	2036	2028	2029	2033	2028	2033
1	8/31/2005 10:22	500 psf, 0.3, open	488	487	482	524	526	603	623	646	677	713	750	781	814	850	868	892	916	928	940	931	901	871	346	245
2	8/31/2005 10:32	500 psf, 0.3, open	490	485	482	524	528	601	621	645	677	711	750	780	811	849	866	887	914	924	938	930	897	865	347	248
3	8/31/2005 10:35	500 psf, 0.3, 1/2	490	488	484	526	528	604	624	648	680	714	752	782	814	852	869	893	916	927	940	931	900	866	345	251
4	8/31/2005 10:36	500 psf, 0.3, closed	491	487	484	528	529	604	626	648	680	716	753	782	816	853	871	893	920	930	943	934	902	868	347	251
5	8/31/2005 10:40	500 psf, 0.4, closed	484	479	472	515	526	597	624	649	686	725	767	800	832	875	894	919	947	960	976	970	944	904	382	226
6	8/31/2005 10:43	500 psf, 0.5, closed	475	469	452	502	526	596	625	655	696	744	786	821	858	900	924	948	979	995	1016	1005	991	950	423	200
7	8/31/2005 10:45	500 psf, 0.6, closed	463	456	425	502	534	607	638	673	717	768	812	852	892	940	966	990	1027	1044	1075	1064	1056	1002	496	214
8	8/31/2005 10:46	500 psf, 0.6, closed																								
9	8/31/2005 10:47	500 psf, 0.7, closed	453	446	404	465	501	556	593	628	668	714	763	796	837	881	911	934	975	991	1024	1004	1018	963	546	250
10	8/31/2005 11:02	1000 psf, 0.3, closed	963	960	955	1035	1041	1188	1229	1276	1338	1401	1473	1532	1598	1669	1703	1749	1792	1817	1832	1826	1758	1685	689	504
11	8/31/2005 11:04	1000 psf, 0.4, closed	954	951	939	1016	1041	1174	1228	1280	1352	1428	1501	1569	1635	1716	1752	1798	1844	1873	1901	1896	1842	1763	757	460
12	8/31/2005 11:05	1000 psf, 0.5, closed	936	931	894	992	1047	1179	1240	1305	1384	1470	1551	1622	1693	1778	1823	1877	1933	1965	2008	1996	1971	1881	856	392
13	8/31/2005 11:07	1000 psf, 0.6, closed	913	906	846	992	1065	1202	1268	1339	1428	1521	1607	1678	1755	1847	1893	1944	2015	2050	2103	2086	2076	1969	1002	419
14	8/31/2005 11:08	1000 psf, 0.7, closed	892	882	802	909	984	1079	1149	1217	1299	1388	1472	1537	1620	1706	1761	1810	1884	1916	1975	1944	1969	1854	1097	471
15	8/31/2005 11:15	1500 psf, 0.3, closed	1430	1429	1423	1539	1552	1758	1826	1893	1986	2072	2176	2260	2353	2456	2504	2569	2647	2682	2706	2698	2597	2487	1019	769
16	8/31/2005 11:16	1500 psf, 0.4, closed	1425	1420	1400	1520	1559	1755	1846	1922	2032	2147	2258	2355	2454	2573	2626	2698	2778	2824	2862	2854	2785	2656	1148	673
17	8/31/2005 11:18	1500 psf, 0.5, closed	1404	1397	1348	1492	1570	1760	1860	1950	2075	2200	2317	2418	2525	2650	2716	2795	2869	2919	2972	2953	2915	2781	1269	565

TP	N/A	N/A	PBC1	PBC2	PMDI	PMDO	PBPVI	PBPVO	PVAC	TCI1	TCI2	TCO1	TCO2	TCD	TCLIN	TCLIS	TCLBN	TCLBS	TON	TOS	Date	Time
0	8/31/2005 10:02	VOID	2033	2029	2025	2039	2036	2036	2025	73	74	75	75	75	75	75	75	75	72	72	8/31/2005	9:10:31 AM
1	8/31/2005 10:22	500 psf, 0.3, open	511	500	484	496	495	492	272	70	70	261	262	269	243	242	-454	-454	70	69	8/31/2005	10:14:04 AM
2	8/31/2005 10:32	500 psf, 0.3, open	511	500	484	499	496	492	276	71	71	270	272	279	256	255	-454	-454	72	71	8/31/2005	10:24:20 AM
3	8/31/2005 10:35	500 psf, 0.3, 1/2	514	504	486	499	502	494	277	72	72	272	274	281	258	258	-454	-454	72	72	8/31/2005	10:27:03 AM
4	8/31/2005 10:36	500 psf, 0.3, closed	517	507	489	499	506	494	273	72	72	273	274	282	259	259	-454	-454	72	72	8/31/2005	10:28:03 AM
5	8/31/2005 10:40	500 psf, 0.4, closed	517	504	483	496	505	481	279	72	72	264	268	276	261	258	-454	-454	72	72	8/31/2005	10:31:25 AM
6	8/31/2005 10:43	500 psf, 0.5, closed	523	508	477	491	505	473	276	72	73	253	257	261	260	259	-454	-454	72	73	8/31/2005	10:35:12 AM
7	8/31/2005 10:45	500 psf, 0.6, closed	528	510	471	479	504	459	276	73	73	252	258	256	262	261	-454	-454	73	73	8/31/2005	10:38:11 AM
8	8/31/2005 10:46	500 psf, 0.6, closed																				
9	8/31/2005 10:47	500 psf, 0.7, closed	536	516	467	479	508	452	278	73	74	251	260	258	263	261	-454	-454	73	74	8/31/2005	10:39:28 AM
10	8/31/2005 11:02	1000 psf, 0.3, closed	1011	997	966	981	993	968	282	77	78	287	289	301	287	284	3218	3218	78	78	8/31/2005	10:54:33 AM
11	8/31/2005 11:04	1000 psf, 0.4, closed	1016	998	962	972	994	954	295	78	78	274	279	290	284	282	3218	3218	78	79	8/31/2005	10:56:29 AM
12	8/31/2005 11:05	1000 psf, 0.5, closed	1031	1010	953	964	997	937	288	78	79	266	270	277	283	282	3218	3218	79	79	8/31/2005	10:57:24 AM
13	8/31/2005 11:07	1000 psf, 0.6, closed	1041	1012	940	954	995	919	294	80	80	262	269	267	282	281	-454	-454	80	81	8/31/2005	10:59:16 AM
14	8/31/2005 11:08	1000 psf, 0.7, closed	1043	1011	931	937	994	889	300	80	81	259	268	268	282	279	-454	-454	81	81	8/31/2005	11:00:31 AM
15	8/31/2005 11:15	1500 psf, 0.3, closed	1500	1482	1442	1460	1472	1438	349	81	81	291	294	307	296	293	3218	3218	81	81	8/31/2005	11:06:47 AM
16	8/31/2005 11:16	1500 psf, 0.4, closed	1523	1499	1444	1456	1486	1424	301	82	82	277	282	293	294	292	3218	3218	82	82	8/31/2005	11:08:21 AM
17	8/31/2005 11:18	1500 psf, 0.5, closed	1535	1505	1429	1440	1486	1402	252	82	82	267	269	277	290	289	-454	-454	82	82	8/31/2005	11:10:41 AM

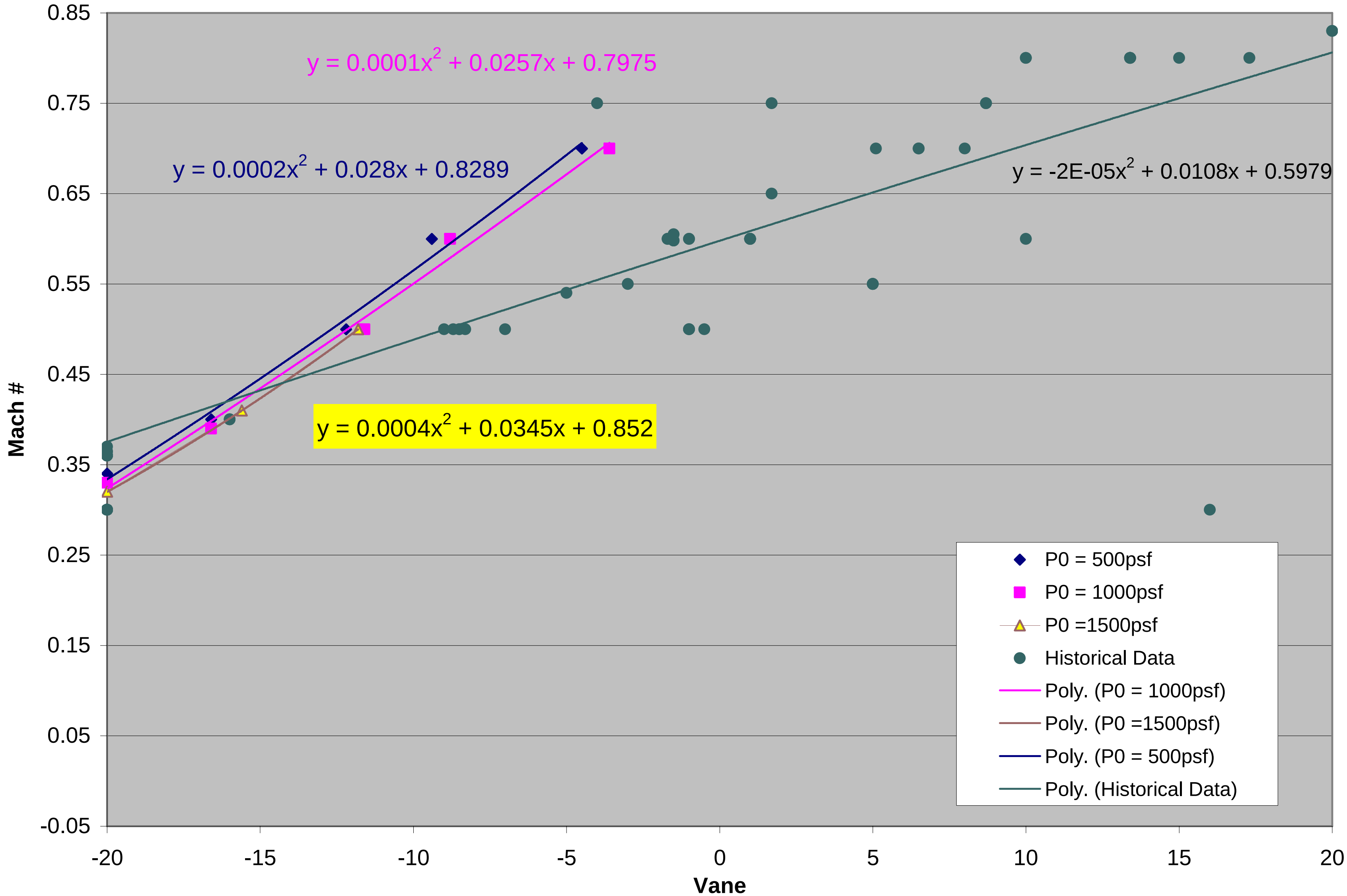


Figure D-1. Historical verses first shakedown run with Mach output verses vane angle setting

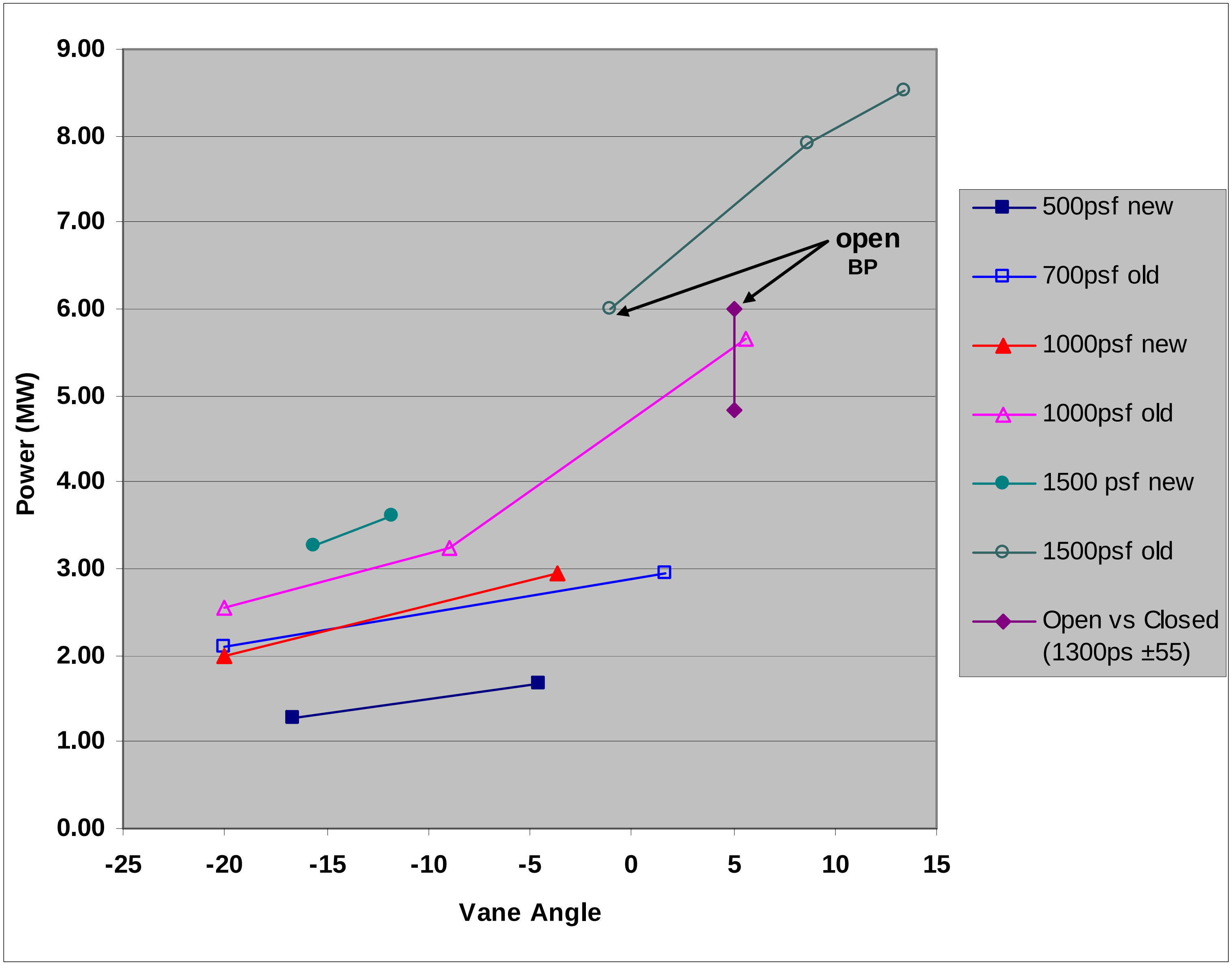


Figure D-2. Power consumption from first run verses vane angle and pressure

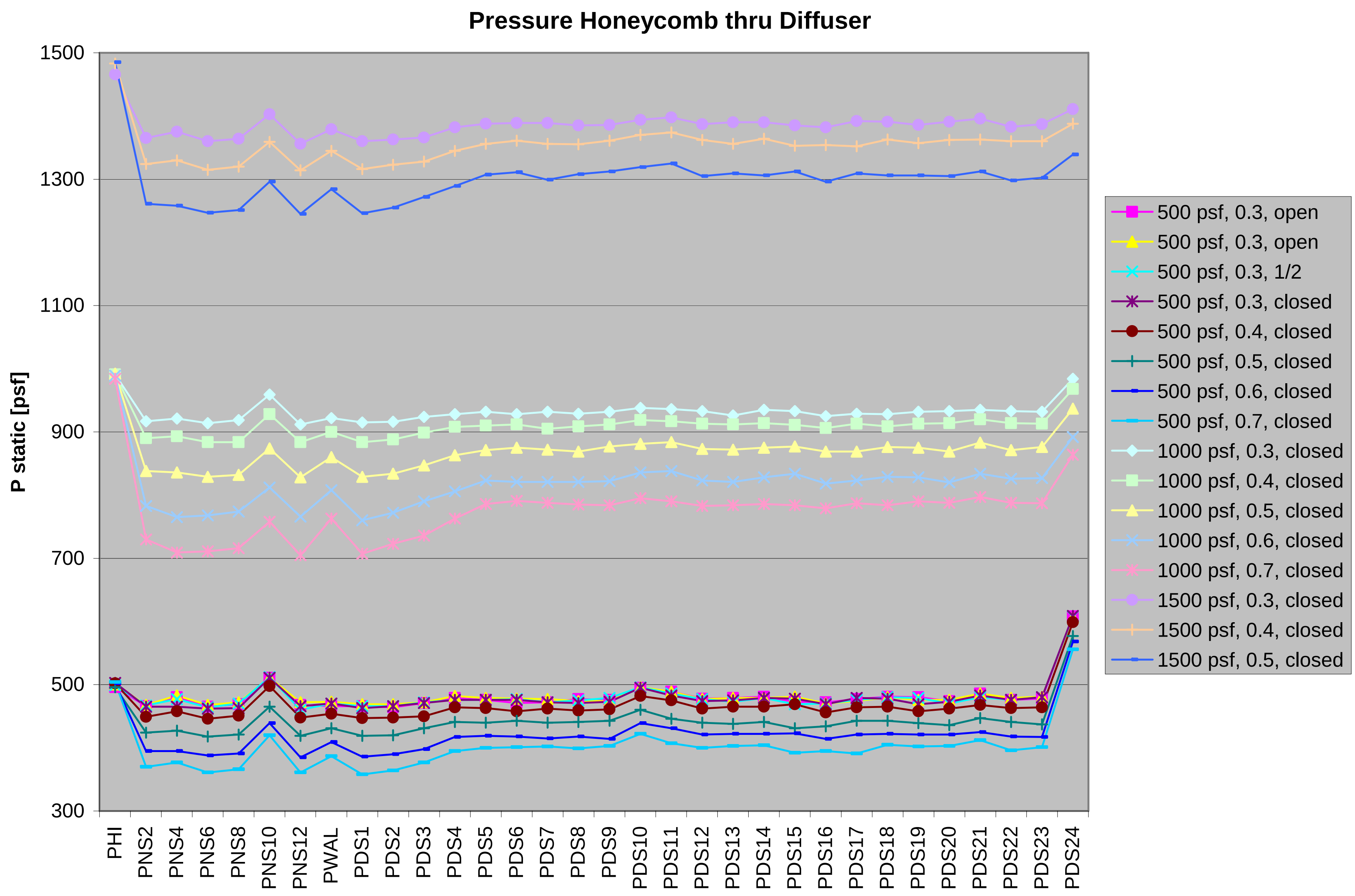


Figure D-3. Pressure Profile through throat, test section and diffuser of first run

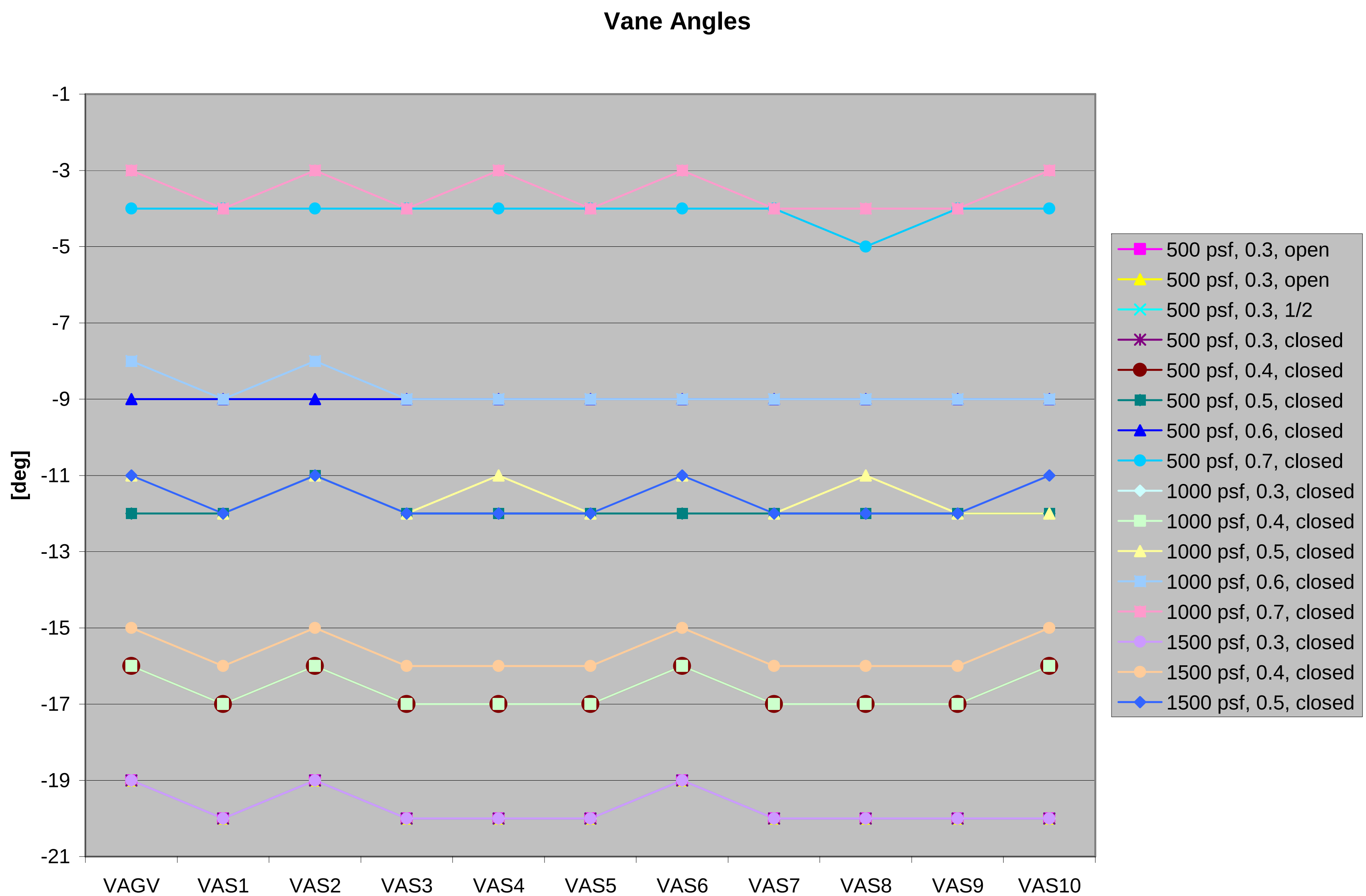


Figure D-4. Vane angle setting (rounded to nearest integer) from first run

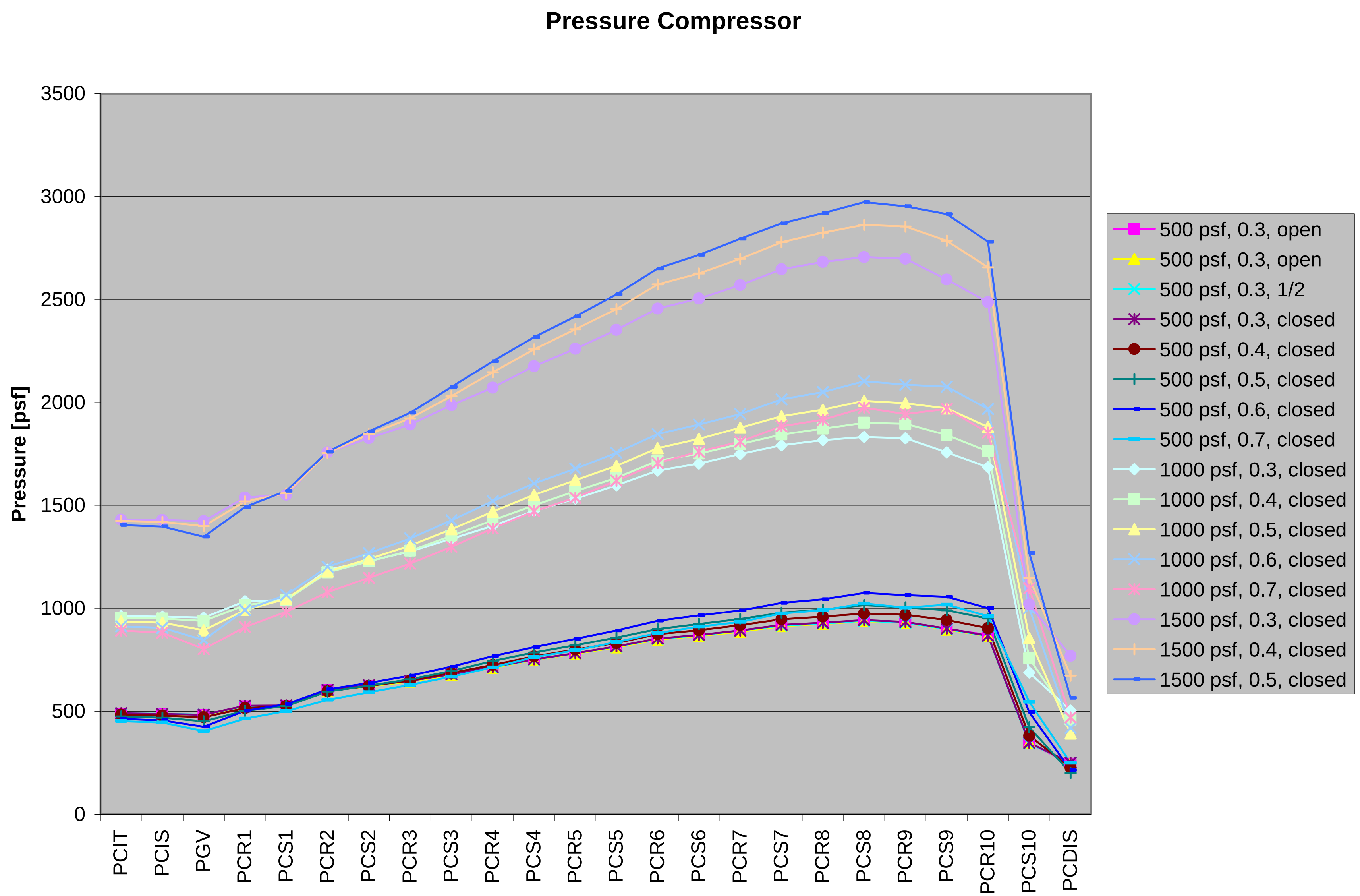


Figure D-5. Compressor pressure profile from first run

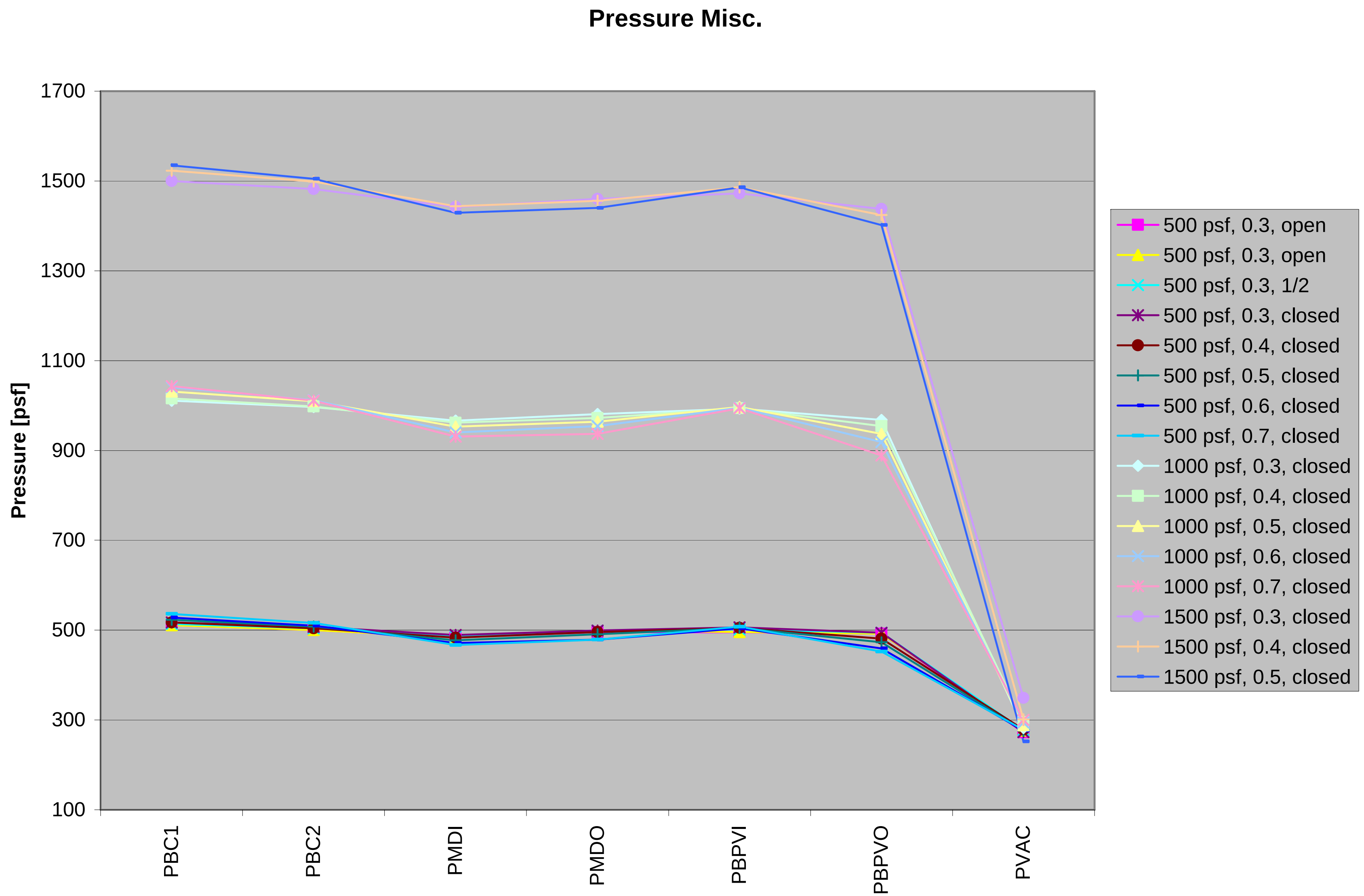


Figure D-6. Pressure through other sections of tunnel from first run

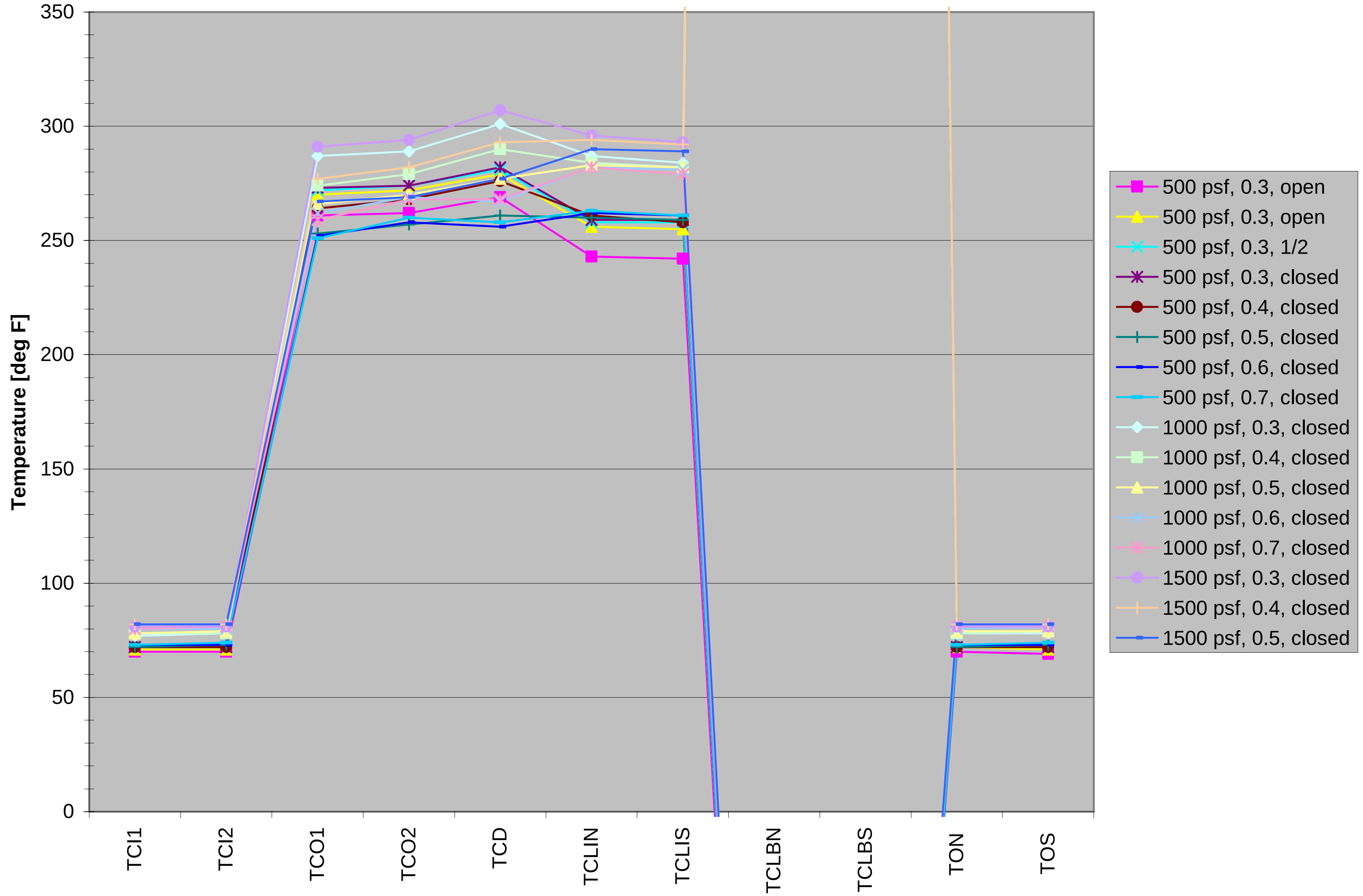


Figure D-7. Temperature profile of tunnel on first run

Table D-4. Oct 4: second subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility
Subsonic Calibration - Shakedown of Facility
2005: run # 2

			Independent Variables					Response Variables				Comments	Voltage 2400	Voltage 6900	
Time	**Data Point**	**Test Set Point**	**Pressure [psf]**	**Set Mach Number**	**Vanes**	**Bypass**	**Diffuser Walls**	**Vane Angle**	**Actual Mach**	**Current on 3500 [Amps]**	**Current on 5000 [Amps]**	**Start @ 1200 Sync @ 1327**	**Power 3500 [kW]**	**Power 5000 [kW]**	**Total Power [MW]**
		~~1~~	~~500~~	~~0.3~~		~~Open~~	~~Open~~						~~0~~	~~0~~	~~0.00~~
1332	1	2	500	0.3		Open	Walls Set	-20	0.29	438	38	Started with walls already set	1051	262	1.31
1334	2	3	500	0.3		1/2	"	-20	0.3	353	51		847	352	1.20
1335	3	4	500	0.3		Closed	"	-20	0.34	360	49		864	338	1.20
1137	4	5	500	0.4		Closed	"	-16.6	0.4	353	65		847	449	1.30
1338	5	6	500	0.5		Closed	"	-12.4	0.5	353	84	Surge after. Had to approach fron	847	580	1.43
1340	6	7	500	0.6		Closed	"	-9.5	0.6	350	105		840	725	1.56
1342	7	8	500	0.7		Closed	"	-4.5	0.7	350	117		840	807	1.65
		9	500		5	Closed	"	5	0.7	357	106	Repeat from prev. observations	857	731	1.59
1349	8	10	1000	0.3		Closed	"	-20	0.33	356	171		854	1180	2.03
1351	9	11	1000	0.4		Closed	"	-16.6	0.4	350	200		840	1380	2.22
1353	10	12	1000	0.5		Closed	"	-12.4	0.5	346	242	Raise Rheostat going to next	830	1670	2.50
1355	11	13	1000	0.6		Closed	"	-9	0.6	417	261	Raise Rheostat going to next	1001	1801	2.80
1357	12	14	1000	0.7		Closed	"	-4.5	0.7	516	251		1238	1732	2.97
1406	13	15	1500	0.3		Closed	"	-20	0.33	534	231		1282	1594	2.88
1408	14	16	1500	0.4		Closed	"	-16.2	0.4	526	281	Raise Rheostat going to next	1262	1939	3.20
1410	15	17	1500	0.5		Closed	"	-12	0.5	584	332		1402	2291	3.69
			2000							632	325	Power check on approach.	1517	2243	3.76
1421	16	18	2250	0.3		Closed	"	-20	0.32	635	378	90% Power Condition (10 min., data every 2 min)	1524	2608	4.13
	17	19	"	"		"	"	-20	0.32	655	379		1572	2615	4.19
1424	18	20	"	"		"	"	-20	0.32	641	375		1538	2588	4.13
1426	19	21	"	"		"	"	-20	0.32	640	378		1536	2608	4.14
1428	20	22	"	"		"	"	-20	0.32	638	378		1531	2608	4.14
1430	21	23	"	"		"	"	-20	0.32	639	377		1534	2601	4.13
		~~24~~	~~2250~~		~~-20~~	~~Closed~~	~~"~~	~~-20~~					~~0~~	~~0~~	~~0.00~~
1437	22	25	1450	0.7		Closed	"	-2.6	0.7	672	373	90% Power Condition (10 min., data every 2 min)	1613	2574	4.19
1439	23	26	"	"		"	"	-2.6	0.69	676	374		1622	2581	4.20
1441	24	27	"	"		"	"	-2.6	0.7	681	372		1634	2567	4.20
1443	25	28	"	"		"	"	-2.6	0.7	667	373		1601	2574	4.17
1445	26	29	"	"		"	"	-2.6	0.69	670	371		1608	2560	4.17
1447	27	30	"	"		"	"	-2.6	0.7	670	373		1608	2574	4.18
		~~31~~	~~1450~~		~~-20~~	~~Closed~~	~~"~~						~~0~~	~~0~~	~~0.00~~

1451 Unload & Unsynched M=.29 P0=515
1515 Stopped rotation (end of shutdown)

Table D-5. Oct 5: third subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility

Subsonic Calibration - Shakedown of Facility

2005: run # 3 Oct 5,2005

Time	Data Point	Test Set Point	Independent Variables					Response Variables				Comments	Voltage 2400	Voltage 6900	
			Pressure [psf]	Set Mach Number	Vanes	Bypass	Diffuser Walls	Vane Angle	Actual Mach	Current on 3500 [Amps]	Current on 5000 [Amps]		Power 3500 [kW]	Power 5000 [kW]	Total Power [MW]
	0	off													
1300	**1**	baseline										compressors off			
1324	**2**	baseline							**0.14**			Unsynch'ed - 1000PRM			
												Bypass was open M0.6 at V=+3 or+4			
1345	3	1	700	0.7		Closed	Walls Set	-1	0.73	440	164	Push to Mach 0.8	1056	1132	2.19
1346	4	2	700		above +2	Closed	"	1.1					0	0	0.00
1347	5	3	700		above +2	Closed	"	3.3	0.72				0	0	0.00
1348	6	4	700		above +2	Closed	"	5	0.71	437	151		1049	1042	2.09
1349	7	5	700		above +2	Closed	"	7	0.67	436	147		1046	1014	2.06
1350	8	6	700		above +2	Closed	"	9	0.64	438	139		1051	959	2.01
1351	9	7	700		above +2	Closed	"	11	0.61				0	0	0.00
1354	10	8	700		above +2	20% open	"	11	0.59	437	137	goal: run up to 0.8 or v=+10, whichever comes first.	1049	945	1.99
		11	2116 to open doors				CLOSED					"Model Change" Un-synched @ : Sync @ :	0	0	0.00
1407	11		500	0	-20	open	CLOSED					UNSYNC. had error in operation: SAFE closed & locked V5… should not have been turned YET.			
1421	12		1940	0	-20	open	CLOSED					UNLOCK WINDOWS Windows open @ 2:28(ish) Windows closed @ 2:30			

Table D-6. Oct 11: fourth subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility
Subsonic Calibration - Shakedown of Facility
2005: run # 4 date: 11 Oct 2005

		Independent Variables					Response Variables				Comments	Voltage 2400	Voltage 6900	
Time	**Test Set Point**	**Pressure [psf]**	**Set Mach Number**	**Vanes**	**Bypass**	**Diffuser Walls**	**Vane Angle**	**Actual Mach**	**Current on 3500 [Amps]**	**Current on 5000 [Amps]**	**Attempt to lag vanes to push to Mach 0.8**	**Power 3500 [kW]**	**Power 5000 [kW]**	**Total Power [MW]**
1319	1	500	0.7	-4.5	Closed	Set	-4.5	0.71	379	113		910	780	1.69
1321	2	500		-2.5	Closed	Set	-2.6	0.73	379	108		910	745	1.65
1322	3	500		-0.5	Closed	Set	-0.4	0.74	377	112		905	773	1.68
1324	4	500		1.5	Closed	Set	1.4	0.74	374	110	(at angle =0, M=.74)	898	759	1.66
1325	5	500		3.5	Closed	Set	3.5	0.73	380	106		912	731	1.64
1327	6	500		5.5	Closed	Set	5.5	0.71	372	101	PS slightly lower	893	697	1.59
1328	7	500		5.5	Closed	Set	5.5				PS "normal"			
1329	8	500		5.5	Closed	Set	5.5	0.7			Lag Guide Vane +1			
1329	9	500		5.5	Closed	Set	5.5	0.71	379	107	Lag Guide Vane -1	910	738	1.65
1330	10	500		7.5	Closed	Set	5.5	0.72	379	107	Lag Guide Vane -2	910	738	1.65
1332	11	500		-4.5	Closed	Set	7.5	0.68	375	101	w/ Lag GV -2	900	697	1.60
											Since Mach lowered with GV lagged, attempt to study effect of moving more than just GV			
1334	12	500		-4.5	Closed	Set	-4.5	0.71			Lag: GV -2/ 1st -0.8			
1335	13	500		-4.5	Closed	Set	-4.5	0.71			Lag: GV -2/ 1st -1/ 2nd -.5			
1337	14	500		-4.5	Closed	Set		0.71			Lag: GV -2/ 2nd -0.5			
1338	15	500		-2.5	Closed	Set	-2.5	0.73			Lag: GV -2/ 2nd -0.5			
1340	16	500		-0.5	Closed	Set	-0.5	0.75	370	116	Lag: GV -2/ 2nd -0.5	888	800	1.69
1341	17	500		1.5	Closed	Set	1.5	0.75	378	117	Lag: GV -2/ 2nd -0.5	907	807	1.71
1342	18	500		3.5	Closed	Set	3.5	0.74			Lag: GV -2/ 2nd -0.5			
1344	19	500		5.5	Closed	Set	5.5	0.71			Lag: GV -2/ 2nd -0.5			
1344	20	500		3.5	Closed	Set	3.5	0.72			Lag: 2nd -0.5			
1345	21	500		3.5	Closed	Set	3.5				Lag NONE			
1346	22	500		3.5	Closed	Set	3.5	0.74			Lag GV -2			
1346	23	500		4	Closed	Set	4	0.74	372	108	Lag GV -2	892.8	745.2	1.64
	24	500		4.5	Closed	Set	4.5	0.73			Lag GV -2			

Wall Setting: 14.52, 14.33, 14.83

Table D-7. Oct 13: fifth subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility

Subsonic Calibration - Shakedown of Facility

2005: run # 5 date: 13 Oct 2005

		Independent Variables				RESPONSE Variables			Comments / NOTES	Voltage 2400	Voltage 6900	
Time	Test Set Point	Pressure [psf]	Vanes	Bypass	Diffuser Walls	Actual Mach	Current on 3500 [Amps]	Current on 5000 [Amps]	Attempt to lag vanes by 5° to push to Mach 0.8	Power 3500 [kW]	Power 5000 [kW]	Total Power [MW]
1300	1: initial prior to sync											
1334	2: after sync before close bypass, walls set											
1334	3	500	-20	Closed	Set	0.34	285	74		684	511	1.19
1335	4	500	-15	"	"							
1336	5	500	-15	"	"				Lag Guide Vane 5°			
1337	6	500	-10	"	"	0.57	284	127		682	876	1.56
1338	7	500	-5	"	"	0.72	284	151		682	1042	1.72
1338	8	500	-3	"	"	0.74	283	154		679	1063	1.74
1339	9	500	-1	"	"	0.76			P1 Ch2 has a lot of waviness to it… this is associated with excess noise from the vacuum pumps			
1340	10	500	0	"	"	0.76						
1341	11	500	1	"	"	0.77						
1342	12	500	2	"	"	0.77	284	151		682	1042	1.72
1342	13	500	3	"	"	0.77						
1343	14	500	4	"	"	0.76						
1344	15	500	5	"	"	0.74			Larry Reiker showed up and mentioned moving the walls had an effect on attaining M0.8 to 0.9 flow. Third wall will vibrate if in wrong position.			
1357	16	500	1	"	Close 1/2" more	0.74			walls: 13.94,13.95,13.95			
1358	17	500	1	"	near Set	0.76			walls: 14.3,14.39,14.37			
1359	18	500	1	"	Open	0.77			walls: 14.87,15.4,14.87			
1401	19	500	1	"	"	0.79	278	156	Lag GV 7.5°	667	1076	1.74
1401	20	500	0	"	"	0.78			"			
1401	21	500	2	"	"	0.79			Lag GV 10°			
1403	22	500	2	"	"	0.8			"			
1403	23	500	3	"	"	0.8			"			
1404	24	500	4	"	"	0.79			"			
1404	25	500	1	"	"	0.79			Lag GV 11°			
1405	26	500	1	"	"	0.8			Lag GV 12°			
1405	27	500	0	"	"	0.8			"			

SET Wall Setting: 14.52, 14.33, 14.83

Table D-8a. Oct 20: sixth subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility
Subsonic Calibration - Shakedown of Facility
2005: run 6 date: 20 Oct 05

		Independent Variables				Response Variables										Comments	
Time	**Test Set Point**	**Pressure [psf]**	**Main Vane Angle**	**Bypass**	**Diffuser Walls**	**Vane Angle Combo** (noted only if different than Main Vane Angle)							**Actual Mach**	**Current on 3500 [Amps]**	**Current on 5000 [Amps]**		**Total Power [MW]**
						Guide Vane	Vane 1	Vane 2	Vane 3	Vane 8	Vane 9	Vane 10					
1021	1															warm up	0.00
1047	2															Synchronized	0.00
1052	3	1000	-20	closed	open								0.34				0.00
1053	4	"	-20	open	"								0.3	264	211	position of Amps	2.09
1055	5	"	-15	closed	"								0.45			for TSP 14 thru ~27 is approx	0.00
1056	6	"	-15	open	"								0.38				0.00
1057	7	"	-10	closed	"								0.58	307	239		2.39
1058	8	"	-10	open	"								0.5	441	239		2.71
1059	9	"	-5	open	"								0.58	507	232		2.82
1100	10	"	-5	closed	"								0.71				0.00
1101	11	"	0	closed	"								0.75	511	270		3.09
1101	12	"	0	open	"								0.6				0.00
1102	13	"	5	open	"								0.58	504	261		3.01
1103	14	"	5	closed	"								0.72				0.00
1104	15	"	10	open	"											not fully to next position (V~=+7)	0.00
	16	"	10	open	"								0.53	510	256		2.99
1107	17	"	0	closed	"							-5	0.74			attempt to improve compr. profile	0.00
1108	18	"	0	"	"						-5	-5	0.74	499	268		3.05
1110	19	"	0	"	"	-5							0.78			impact of guide vanes	0.00
1111	20	"	0	"	"	-10							0.8	509	248		2.93
1111	21	"	0	"	"	-15							0.82				0.00
1113	22	"	-2.3	"	"	-17							0.8				0.00
1113	23	"	-5	"	"	-20							0.75	502	224		2.75
1117	24	"	5	"	"								0.72	493	278		3.10
1118	25	"	"	"	"	0							0.75	494	279		3.11
1119	26	"	"	"	"	-5							0.78	512	274		3.12
1120	27	"	"	"	"	-10							0.81	506	286		3.19
1121	28	"	"	"	"	-10	2.5						0.85	489	297	attempting to improve compressor	3.22
1122	29	"	"	"	"	-10	0						0.86	512	291	efficiency & pressure profile	3.24
1124	30	"	"	"	"	-10	-2.5						0.87	499	241		2.86
1125	31	"	"	"	"	"	"			2.5			0.87	499	259		2.98
1126	32	"	"	"	"	"	"			0			0.87	511	271		3.10
1128	33	"	"	"	"	"	"			0	2.5		0.86	509	287		3.20
1128	34	"	"	"	"	"	"			0	0		0.86	492	303		3.27
1129	35	"	"	"	"	"	"			2.5	0		0.87	514	308		3.36
1130	36	"	"	"	"	"	"				0		0.86	495	315		3.36

Table D-8b. Oct 20: sixth subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility

Subsonic Calibration - Shakedown of Facility

2005: run 6 date: 20 Oct 05

		Independent Variables				Response Variables										Comments	
Time	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls	Vane Angle Combo (noted only if different than Main Vane Angle)							Actual Mach	Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
						Guide Vane	Vane 1	Vane 2	Vane 3	Vane 8	Vane 9	Vane 10					
1021	1															warm up	0.00
1131	37	1000	5	closed	open	-10	-2.5	2.5			0		0.86	507	312		3.37
1132	38	"	"	"	"	"	"	"			0	2.5	0.86	500	311		3.35
1132	39	"	"	"	"	"	"	"			0	0	0.86	506	312		3.37
1134	40	"	"	"	"	"	"	"					0.86	498	304		3.29
1135	41	"	"	open	"	"	"	"					0.69	497	313		3.35
1136	42	"	"	closed	"	-5	"	"					0.85	497	326		3.44
1137	43	"	"	closed	"	0	"	"					0.81	503	307		3.33
1139	44	"	"	closed	"		"	"					0.76	508	327		3.48
1140	45	"	0	closed	"		2.5	5					0.76	499	223	keep lag the same while change	2.74
1141	46	"	-5	closed	"		-2.5	0					0.68	500	258	Main Vane Angle	2.98
1143	47	"	-10	closed	"		-7.5	-5					0.56	511	265		3.05
1144	48	"	-15	closed	"	-20	-12.5	-10					0.42	514	250	max-ed out GV	2.96
1145	49	"	-15	open	"	-20	-12.5	-10					0.36	515	215		2.72
1148	50	"	5	open	"	0	2.5						0.61	506	161		2.33
1148	51	"	5	closed	"	0	2.5						0.76	510	159		2.32
1150	52	"	5	"	"	-10	-2.5						0.86	505	264		3.03
1150	53	"	5	"	"	-10	-2.5	0					0.85	520	256		3.01
1152	54	"	5	"	"	"	-2.5	0	2.5				0.85	521	300		3.32
1152	55	"	5	"	"	"	0	0	2.5				0.83	511	299		3.29
1156	56	"	5	"	"	"	-5	2.5					0.86	510	293		3.25
1157	57	"	5	"	"	"	-5						0.87	515	314		3.40
1202	58	750	5	"	"	"	-5						0.87	511	207		2.65
1204	59	500	5	"	"	"	-5						0.87	510	106		1.96
	60															un-sync'd cooling down	

Table D-9. Oct 26: seventh subsonic run schedule with outputs

Wright Patterson Tri-Sonic Gas Dynamics Facility

Subsonic Calibration - Shakedown of Facility

2005: run 7 date: 24 Oct 05

			Independent Variables				Response Variables					Comments	
Time	Test Pt Actual	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls	Vane Angle Combo (noted only if different than Main Vane Angle)		Actual Mach	Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
							Guide Vane	Vane 1					REQUEST 3.5MW
808		1								267		Static	0.64
901		2	1000	-20	closed	open			0.34	271	205	After Sync	2.06
903		3	"	-15	"	"			0.45	370	169	Same As Run 6 Pt 5	2.05
904		4	"	-10	"	"			0.57	416	201	Same As Run 6 Pt 7	2.39
906		5	"	-5	"	"			0.72	410	287	Same As Run 6 Pt 10	2.96
907		6	"	0	"	"			0.77	589	228	Same As Run 6 Pt 11	2.99
908		7	"	5	"	"			0.74	591	210	Same As Run 6 Pt 14	2.87
910		8	"	5	"	"	0		0.76	592	223	impact of guide vanes Same As Run 6 Pt 25	2.96
911		9	"	"	"	"	-5		0.79	611	235	Same As Run 6 Pt 26	3.09
913		10	"	"	"	"	-10		0.82	607	256	Same As Run 6 Pt 27	3.22
916		11	"	"	"	"	-15		0.84	594	263	IGV lag -20	3.24
917	12	13	"	"	"	"	-10	0	0.87	601	268	Impact of Vane 1	3.29
919	13	14	"	"	"	"	-10	-5	0.87	598	279	Same As Run 6 Pt 57	3.36
920	14	15	"	"	"	"	-15	0	0.87	591	278		3.34
921	15	16	"	"	"	"	-15	-5	0.87	612	286		3.44
924	16	19	"	7.5	"	"	-7.5	-2.5	0.87	600	283	Impact of further vane angle (same lag as 14)	3.39
925	17	20	"	10	"	"	-5	0	0.87	609	280	(same lag as pt 14)	3.39
928	18	21	"	7.5	"	"	-12.5	-2.5	0.87	603	287	(same lag as pt 16)	3.43
929	19	22	"	10	"	"	-10	0	0.87	616	287	(same lag as pt 16)	3.46
930	20	23		"	"	"	-10	-2.5	0.87	595	295	down select final vane schedule	3.46
933	21	24	"	-20	closed	"			0.35	600	97	Rerun final schedule to obtain performance	2.11
93?	22	26	"	-15	closed	"	?			600	148		2.46
937	23	28	"	-10	closed	"	-15		0.58	465	240		2.77
939	24	30	"	-5	closed	"	-15	-10	0.74	455	299		3.16
941	25	32	"	0	closed	"	-15	-10	0.86	450	328		3.34
943	26	34	"	5	closed	"	-15	-5	0.87	455	337		3.42
944	27	36	"	7.5	closed	"	-12.5	-2.5	0.87	449	337	if desired - see above results	3.40

Table D-10. Nov 7: first Mach 1.5 run schedule with outputs (eighth run

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 1.5 Calibration - Shakedown of Facility

2005: run 8 date: 7 Nov 05

Bypass is CLOSED for all settings

			Independent Variables					Response Variables			Comments	Voltage 2400	Voltage 6900	
Time	**Actual Test Point #**	**Test Set Point**	**Pressure [psf]**	**Main Vane Angle**	**Diffuser Walls 1&2**	**Diffuser Walls 3&4**	**Diffuser Walls 5&6**	**Schlieren Image #**	**Current on 3500 [Amps]**	**Current on 5000 [Amps]**		**Power 3500 [kW]**	**Power 5000 [kW]**	**Total Power [MW]**
705		1	2116	20							Static			0.00
758		2	500	-20				1 @ M0.6			Synchronized			0.00
		3	500	5	1.5	1.5	1.5				max flow 0.75			0.00
811		4	500	10	"	"	"				0.72			0.00
		5	500	15	"	"	"				0.65			0.00
828		6	500	20	"	"	"		303	153	0.56	727	1056	1.78
	skip	7	700	5	1.5	1.5	1.5							0.00
	skip	8	700	10	"	"	"							0.00
		9	700	15	"	"	"				not established			0.00
		10	700	20	"	"	"				not established			0.00
835		11	900	5	1.5	1.5	1.5				max flow 0.8, min 0.6 (bypass open)			0.00
	skip	12	900	10	"	"	"							0.00
	skip	13	900	15	"	"	"							0.00
	skip	14	900	20	"	"	"							0.00
846		15	1100	5	1.5	1.5	1.5		555	237	max flow 0.78	1332	1635	2.97
									578	248	same condition, bypass open	1387	1711	3.10
849		16	1100	10	"	"	"				min .56			
851		17	1100	0	"	"	"				max .85			0.00
	skip	18	1100	20	"	"	"							0.00
857		19	1300	0	1.5	1.5	1.5				max .86			0.00
859		20	1300	5	"	"	"	2-6, 7 when open						0.00
902		21	1300	10	"	"	"		624	260	min .53	1498	1794	3.29
									641	269	same condition, bypass open	1538	1856	3.39
906		22	1300	15	"	"	"				min .48 bypass open - stop running !!			0.00

Wall settings: 13.5, 13.6, 13.18 ±0.02

Table D-11. Nov 8: second Mach 1.5 run schedule with outputs (ninth run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 1.5 Calibration - Shakedown of Facility

2005: run 9 date: 8 Nov 05

***Bypass is CLOSED for all settings**

			Independent Variables						Response Variables			Comments	Voltage 2400	Voltage 6900	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Current on 3500 [Amps]	Current on 5000 [Amps]		Power 3500 [kW]	Power 5000 [kW]	Total Power [MW]
728	14	1	2116	20								warm up			0.00
819	15	2	500	-20								Synchronized			0.00
		12	1100	5	closed (0)	11.5	10.7	11.5				no flow			0.00
		13	1100	5	"	12	"	"				no flow			0.00
	16	14	1100	5	"	12	10.5	"				no flow			0.00
	17	15	1100	5	"	"	10.3	"		537	240		1289	1656	2.94
	18,19	16	1100	5	"	"	10	"				pt 19 as opening?			0.00
	20	17	1100	5	"	"	9.7	"							0.00
	21	18	1100	5	"	10.5	11.25	"							0.00
	22	19	1100	10	"	"	"	"							0.00
	23	20	1100	15	"	"	"	"							0.00
	24	21	1100	15	"	"	10.5	"							0.00
	25	22	1100	15	"	"	"	"							0.00
	26	23	1100	15	10	10.5	10	11.5		469	225		1126	1553	2.68
	27	24	1100	15	closed	"	"	"							0.00
	28	25	1100	15	"	10.1	"	"							0.00
	29	26	1100	15	"	"	9.7	"							0.00
	30	27	1100	15	"	"	9	"							0.00
	31	28	1100	15	"	"	8.5	"							0.00
	32	29	1100	15	"	"	8	"							0.00
	33	30	1100	5	"	10.5	10.5	"							0.00
	34	31	1100	5	"	"	10	"		485	236		1164	1628	2.79
										480	262	opened BP	1152	1808	2.96
	35	32	1100	5	"	"	9.5	"							0.00
	36	33	1100	5	20	10.5	9.5	11.5							0.00
	37	34	1100	5	0	"	10.5	10.5							0.00
	38	35	1100	5	10										0.00
	39	36	1100		20										0.00
	40	37	1100		30										
	41	38	1100	15	0										
	42	39	1100	15								lag IGV -17.5° & Vane1 -15°			

Table D-12. Nov 15: third Mach 1.5 run schedule with outputs (tenth run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 1.5 Calibration - Shakedown of Facility

2005: run 10 date: 15 Nov 05

			Independent Variables						Response Variables							Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Vane Angle Combo (noted only if different than Main Vane Angle)			Mach #	Schlieren Image #	Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
752	1	1	2116	20								NaN				Static	0.00
913	2	2	500	-20					IGV	Vane 1	Vane 2	0.3091				Synchronized	0.00
922	4	3	500	0	closed	13.5	13.6	13.6				0.6111				study bypass effect on compressor profile	0.00
921	3	4	500	"	open	"	"	"				0.9166		259	148		1.64
924	5	5	700	"	open	"	"	"				0.6157					0.00
925	6	6	700	"	closed	"	"	"				0.9535		259	228		2.19
930	8	7	1100	"	closed	"	"	"				0.6095				get pressure bucket again? Yes.	0.00
929	7	8	1100	"	open	"	"	"				0.9504		428	321		3.24
932	9	9	1300	"	open	"	"	"				0.6083		661	321		3.80
933	10	10	1300	"	closed	"	"	"				0.9091				get pressure bucket again? Yes.	0.00
935	11	11	1100	0	closed	13.5	13.6	13.6				0.9408		612	228	verify vane effect	3.04
937	12	12	1100	5	"	"	"	"				0.8066		595	227		2.99
939	13	13	1100	10	"	"	"	"				0.6308		539	226		2.85
942	14	17	1100	5	closed	13.5	13.6	13.6	0			0.8928				optimize compressor	0.00
944	15	18	"	"	"	"	"	"	-5			1.0404		540	276		3.20
948	16	19	"	"	"	"	"	"	-10			1.4524		431	375		3.62
950	17	20	"	"	"	"	"	"	-15			1.2529		344	382		3.46
951	18	22	"	"	"	"	"	"	-10	0		1.3118	1				0.00
954	19	23	"	"	"	"	"	"	-10	-5		1.4288	2	588	363		3.92
957	20	24	"	"	"	"	"	"	-15	0		1.4611	3				0.00
959	21	25	"	"	"	"	"	"	-15	-5		1.4192	4				0.00
1001	22	26	"	"	"	"	"	"	-20	0		1.225	5				0.00
1002	23	27	"	"	"	"	"	"	-20	-5			6				0.00
1004	24	28	"	7.5	closed	13.5	13.6	13.6	-7.5	-2.5		1.3868	7				0.00
1007	25	29	"	10	"	"	"	"	-5	0		1.157	8				0.00
1009	26	32	"	7.5	"	"	"	"	-12.5	-2.5		1.4237	9				0.00
1011	27	33	"	10	"	"	"	"	-10	0		1.4491	10				0.00
1012	28	new	1100	5	closed	13.5	13.6	13.6	-15	-10		1.4552	11				
1014	29	new	"	7.5	"	"	"	"	-12.5	-7.5		1.4595	12				
1015	30	new	"	10	"	"	"	"	-10	-5		1.4599	13				
1018	31	new	"	5	"	"	"	"	-15	-10	0	1.4543					
1022	32	new	"	5	"	13.875	13.875	14	-15	-10		1.4533	14				
1027	33	new	"	5	"	"	"	"	-10	-5		1.4615	15			repeat subsonic schedule	
1032	34	36	1100	5	closed	11.8	11.8	12	-15	-10		0.8772				use best approach & attempt to start flow with closing walls more	0.00
1034	35	38	1100	5	closed	14.5	14.5	14.6	-15	-10		1.4622	16			use best approach & attempt to start flow with closing walls more	

Table D-13. Nov 28: fourth Mach 1.5 run schedule with outputs (11th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 1.5 Calibration - Shakedown of Facility

2005: run 11 date: 28 Nov 05

			Independent Variables						Response Variables								Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Vane Angle Combo (noted only if different than Main Vane Angle)				Mach #	Schlieren Image #	Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
									IGV	Vane 1	Vane 9	Vane 10						
219	1	3	1100	5	closed	13.5	13.6	13.6	-15	-10				1	707	278	improve compressor profile	3.62
221	2	4	"	"	"	13.7	13.6	13.6	-15	-10				2	700	265		3.51
223	3	5	"	"	"	"	"	"	-20	-10				3				0.00
226	4	6	"	"	"	"	"	"	-20	-10		10		4	703	345		4.07
227	5	7	"	"	"	"	"	"	"	"	10	15		5	709	261		3.50
232	6	9	"	"	"	"	"	"	-15	-5	15	"		6	715	245		3.41
235	7	11	"	"	"	"	"	"	"	-5	-2.5	"		7	700	250		3.41
242	8	12	"	"	"	"	"	"	"	-10	"	12.5		8				0.00
245	9	13	"	"	"	"	"	"	"	-10	0	15		9				0.00
248	10	14	"	7.5	"	"	"	"	-12.5	-7.5	-2.5	10		10				0.00
251	11	15	"	5	"	"	"	"	-15	-10	-2.5	10		11				0.00
254	12	27	"	"	"	13.8	13.7	13.7	"	"	"	"		12				0.00
257	13	28	"	"	"	14	13.9	13.9	"	"	"	"		13				0.00
300	14	25	"	"	"	13.4	13.3	13.3	"	"	"	"		14				0.00
301	15	24	"	"	"	13.2	13.1	13.1	"	"	"	"		15				0.00
303	16		"	"	"	13.7	13.6	13.6	"	"	"	"						0.00
303	17		"	"	"	13.5	13.6	13.6	"	"	"	"		16				0.00
305	18		"	"	"	"	"	13.7	"	"	"	"		17				0.00
306	19		"	"	"	"	"	13.8	"	"	"	"		18				0.00
307	20		"	"	"	13.7	13.7	"	"	"	"	"		19				0.00
308	21		"	"	Open				"	"	"	"		20				0.00
309	22		"	"	closed	"	13.6	"	"	"	"	"		21				0.00
310	23		"	"	"	"	13.5	"	"	"	"	"		22				0.00
311	24		"	"	"	"	13.4	"	"	"	"	"		23				0.00
312	25			"	"	13.8	"	"	"	"	"	"		24				0.00
313	26			"	"	"	13.5	"	"	"	"	"		25				0.00
															700	315		3.85

Table D-14. Nov 30: first Mach 1.9 run schedule with outputs (12th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility
Mach 1.9 Calibration - Shakedown of Facility
2005: run 12 date: 30 Nov 05

***Bypass is CLOSED for all settings**

			Independent Variables													Comments	
Time	**Actual Test Point #**	**Test Set Point**	**Pressure [psf]**	**Main Vane Angle**	**Bypass**	**Diffuser Walls 1&2**	**Diffuser Walls 3&4**	**Diffuser Walls 5&6**	**Schlieren Image #**	**Vane Angle Combo (noted only if different than Main Vane Angle)**				**Current on 3500 [Amps]**	**Current on 5000 [Amps]**		**Total Power [MW]**
1223	1	1	2116	20						IGV	Vane 1	Vane 9	Vane 10			warm up	0.00
1255	2	2	500	-20												Synchronized	0.00
1319	3	3	750	0	closed	11.2	10.6	13								attempted at 1100 but too much vibration present in model	0.00
1321	4	4	"	2.5	"	"	"	"									0.00
1324	5,6	12	"	5	"	"	"	"	1,2, V1	0	0					*video of vibration*	0.00
1327	7	13	"	5	"	"	"	"	3	-5	0		7.5				0.00
1331	8	17	"	5	"	"	"	"	4	-15	-10					*Actual Mach: 1.82*	0.00
1334	9	19	"	7.5	"	"	"	"	5	-12.5	-2.5					*With BP open: Mach=1.09*	0.00
1341	12	22	"	10	"	"	"	"		-10	-7.5			389	150		1.97
					open									400	200		2.34
1337	10	23	"	10	closed	"	"	"	6	-10	0						0.00
1339	11	24	"	10	"	"	"	"	7	-10	-5					*Schlieren image 8 with BP open*	0.00
1345	13	25	"	12.5	"	"	"	"	9	-10	0						0.00
1349	14	30	"	5	"	"	"	"	10	-15	-10						0.00
1350	15		"	"	open	"	"	"		"	"					for reference!	
1351	16	31	"	"	closed	"	"	"	11	"	"					either drive GV & V1 futher if seeing improvement OR if maxed out, skip to wall adjustments	0.00
1355	17	32	"	"	"	"	"	"	12	"	"	-2.5	-2.5				0.00
1357	18	33	"	"	"	"	"	"	13	"	"	0	0				0.00
1402	19		"	"	"	11.2	10.4	13	14	"	"	"	"				0.00
1404	20		"	"	"	"	10.8	"	15	"	"	"	"				0.00
1406	21		"	"	"	"	11	"	16	"	"	"	"				0.00
1407	22		"	"	"	"	"	12.8	17	"	"	"	"				0.00
1410	23		"	"	"	"	"	12.5	18	"	"	"	"			*(capture video #3 also)*	0.00
1412	24		"	"	"	"	"	12.25	19	"	"	"	"				0.00
1414	25		"	"	"	11.4	"	"	20	"	"	"	"				0.00
1416	26		"	"	"	"	10.75	"	21	"	"	"	"				0.00
1418	27		"	"	"	"	10.5	"	22	"	"	"	"				0.00

Run notes: Amps stable for test conditions ±20A

Table D-15. Dec 2: second Mach 1.9 run schedule with outputs (13th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 1.9 Calibration - Shakedown of Facility

2005: run 13 date: 2 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables												Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Vane Angle Combo (noted only if different than Main Vane Angle)					Total Power [MW]
1213	1	1	2116	20						IGV	Vane 1	Vane 2	Vane 10	Static	0.00
1243	2	2	500	-20										Synchronized, *dew pt -9*	0.00
		3	700	0	closed	11.2	10.6	13						adjust vanes	0.00
		4	"	1.25	"	"	"	"							0.00
		5		2.5											0.00
		6		3.75											0.00
1252	3	7		5					2	-15	-10	0	-2.5		0.00
1254	4	8		"					3			-2.5	-5	*dew pt -7*	2.04
1257	5	9		"					4				-7.5	*dew pt -9*	0.00
1303	6	10		"					5				-7.5		0.00
	7			"		11.2	10.6	12.6	6						0.00
	8			"		"	"	12.2	7						0.00
1307	9			"		"	"	11.8	8						0.00
				"		"	"	11.5						normal shock in front of model	
				"		"	"	11.6						normal shock in front of model	
1309	10			"		"	"	11.7						took a long time to suck down	0.00
				"		"	10.4	11.8						shock almost ahead of window	
														change temperature control	
1315	11			"		"	10.8	11.8	9,10					very long time Turb area cone forming	0.00
1317	12			"		"	"	12	11,12						0.00
1321	13			"		11.4	"	"	13,14						0.00
1323	14			"		11.6	"	"						jump at Diffuser stage 4	0.00
1325	15			"		11.8	"	"							0.00
1327	16			"		12	"	"							0.00
						11.1	"	"						normal shock in front of model	
						"	"	12.4						normal shock in front of model	
						"	"	12.6						normal shock in front of model	
1336	17			"		11.2	10.6	12.6						recheck of original setting: took a bit more time to estab. Flow	0.00
1340	18			"		"	10.8	12.4	15?						0.00
1346	19			"		"	"	12.8	16,17						0.00
1347	20			"		"	"	13							0.00
	21			"		"	10.6	"							0.00
	22			"		"	"	12.8							0.00
1354	23			"		"	"	12.4							0.00
1356	24			"		"	"	13.2							0.00
1359	25			"		"	"	13.4							0.00
1401	26			"		"	"	13.6							0.00
1403	27			"		"	"	13.8							0.00
1404	28			"		"	"	14						took some time	2.13
1407	29			"		"	10.8	"						shock didn't totallly swallow back	0.00
1413	30			"		"	10.6	"							0.00

Temp controls:

15% open was too far: temp went to 105 on DAQ

20% was about right

25% was too low: didn't change

Table D-16a. Dec 8: Mach 2.3 run schedule with outputs (14th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 2.3 Calibration - Shakedown of Facility

2005: run 14 date: 6 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													**Comments**	
Time	**Actual Test Point #**	**Test Set Point**	**Pressure [psf]**	**Main Vane Angle**	**Bypass**	**Diffuser Walls 1&2**	**Diffuser Walls 3&4**	**Diffuser Walls 5&6**	**Schlieren Image #**	**Vane Angle Combo (noted only if different than Main Vane Angle)**				**Current on 3500 [Amps]**	**Current on 5000 [Amps]**		**Total Power [MW]**
										IGV	Vane 1	Vane 9	Vane 10				
	1	1	2116	20												Static	0.00
926	2,16	2	500	-20												Synchronized (run BL pitot probe in:1-15)	0.00
931	3,17	3	700	0	closed	12.5	10.6	12.7	1					238	109	adjust vanes, *dew pt -17, Mach 2.23*	1.32
									2					239	165	*with bypass open*	1.71
93?	4,18	4	"	5	"	"	"	"								*Mach 2.23*	0.00
944	7/8,21	5	"	7.5	"	"	"	"								*Mach 2.24*	0.00
938	5,19	11	"	0	"	"	"	"	3	-5		-5	-5	237	123	lag vanes to improve flow, *dew pt -19, M2.23*	1.42
941	6,20	12	"	0	"	"	"	"		-5	-5	-5	-7.5			*attempt to improve temp*	0.00
												0	-5	242	197	*with bypass open*	1.94
948	9,22	12	"	5	"	"	"	"		0	0	0	-5	239	131	*video taken, dew pt -26*	1.48
951	10,23	13	"	5	"	"	"	"		-5	0	0	-5			*Dew Pt -25*	0.00
954	11,24	14	"	5	"	"	"	"		-5	-5	"	"				0.00
957	12,25	15	"	5	"	"	"	"		-10	-5	"	"				0.00
		16	"	5	"	"	"	"		-10	-10					*seeing IGV move too much*	0.00
1003	13,26	17	"	5	"	"	"	"		-5	0	-2.5	-7.5			*also movement in V1, spike at (D?)10, drop & crawl back @ 12*	0.00
1012	15,28	20	"	7.5	"	"	"	"		-7.5	-5	0	-5			*IGV moving too much*	0.00
1007	14,27	21	"	7.5	"	"	"	"		-7.5	-2.5	0	-5			*dew pt -21, run pitot (29-40)*	0.00
1042	16,41	22	"	10	"	"	"	"		-5	-2.5	0	-2.5			*dew pt -29*	0.00
	17,42	27	"	10	"	"	"	"		-5	-2.5	0	-10				0.00
	18,43	30	"	5	"	"	"	"		-10	-5	-2.5	-5	235	145	"best" settings (?)	1.56
	19/20,44	31	"	5	"	"	"	"		-5	0	0	-5			either drive GV & V1 futher if seeing improvement OR if maxed out, skip to wall adjustments	0.00
	21/22,45	32	"	0	"	"	"	"		-5	-5	-5	-10			* No start at v=0, GV,V1=-5, V9=-15, V10=-20	0.00
1113	24,46	37	"	0	"	12.4				-5	-5	-5	-10			open/close 1st	0.00
111?	25,47	38	"	"	"	12.3				"	"	"	"				0.00
1116	26,48	39	"	"	"	12.6				"	"	"	"				0.00

Table D-16b. Dec 8: Mach 2.3 run schedule with outputs (14th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 2.3 Calibration - Shakedown of Facility

2005: run 14 date: 6 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													Comments	
Time	**Actual Test Point #**	**Test Set Point**	**Pressure [psf]**	**Main Vane Angle**	**Bypass**	**Diffuser Walls 1&2**	**Diffuser Walls 3&4**	**Diffuser Walls 5&6**	**Schlieren Image #**	**Vane Angle Combo (noted only if different than Main Vane Angle)**				**Current on 3500 [Amps]**	**Current on 5000 [Amps]**		**Total Power [MW]**
	1	1	2116	20						IGV	Vane 1	Vane 9	Vane 10			Static	0.00
1117	27,49	40	"	"	"	12.7				"	"	"	"				0.00
1119	28,50	41	"	"	"	12.5	10.5			"	"	"	"	235	135	open/close 1st, *dew pt -36*	1.50
1120	29,51	42	"	"	"		10.4			"	"	"	"				0.00
1121	30,52	43	"	"	"		10.7			"	"	"	"				0.00
1122	31,53	44	"	"	"		10.8			"	"	"	"				0.00
1123	32,54	45	"	"	"		10.6	12.6		"	"	"	"			open/close 1st	0.00
1124	33,55	46	"	"	"			12.5		"	"	"	"				0.00
1125	34,56	47	"	"	"			12.8		"	"	"	"				0.00
1126	35,57	48	"	"	"			12.9		"	"	"	"				0.00
1141	36,58	49	"	"	"	11.5	10.6	12.7		"	"	"	"			combine best settings & fine tune… start with walls that made the best impact	0.00
1142	37,59	50	"	"	"	10.73	10.6	12.7		"	"	"	"				0.00
1143	60	51	"	"	"	10.73	9.5	12.7	pic @ 1145	"	"	"	"			*poor start*	0.00
1147	38,61	52	"	"	"	10.73	9.5	11		"	"	"	"				0.00
		53	"	"	"	13	11.1	13.2		"	"	"	"			*no start*	0.00
1204	39,62	54	"	"	"	12.75	10.85	12.95		"	"	"	"				0.00
1207	40,63	55	"	"	"	12.3	10.4	12.5		"	"	"	"				0.00
1211	41,64	56	"	"	open					"	"	"	"			*for reference (@ idle)*	0.00

Table D-17a. Dec 12: first Mach 3.0 run schedule with outputs (15th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 3.0 Calibration - Shakedown of Facility

2005: run 15 date: 12 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables														Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Vane Angle Combo (noted only if different than Main Vane Angle)				Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
										IGV	Vane 1	Vane 9	Vane 10				
122?	1	1	2116	20												Static (pts 2-15 BL probe)	0.00
		2	500	-20												Synchronized	0.00
		3	700	0	75%	10.18	7.8	8.5								*no flow*	0.00
		4	"	"	50%	"	"	"								*no flow*	0.00
		5	"	"	40%	"	"	"								*no flow*	0.00
		6	"	"	20%	"	"	"								*no flow*	0.00
		7	"	"	0%	"	"	"								*some shocks forming*	0.00
		10	"	"	40%	"	"	"								*no flow*	0.00
		11	"	"	20%	"	"	"								*no flow*	0.00
		13	"	0	75%	11.5	10.5	10.5									0.00
133?	2,16	17	"	"	0%	"	"	"								*weak shocks formed*	0.00
1341	3,17	23	"	0	0	"	"	"		-5						lag vanes to improve flow *(when BP20, no go) weak shocks at BP 0*	0.00
1343	4/5,18/19	24	"	0	"	"	"	"		-5	-5					*when BP 20, weak shocks*	0.00
1345	6,20	25	"	5	"	"	"	"		0	0						0.00
1348	7,21	26	"	5	"	"	"	"		-5	0					*when BP 20 weak shocks*	0.00
1350	8,22	27	"	5	"	"	"	"		-5	-5					*this setting did not help the profile***	0.00
1352	9,23/24	28	"	5	"	"	"	"	1	-10	-5			219	147	*Mach 2.78 Dew Pt -29.5*	1.54
1355	10,25	29	"	5	"	"	"	"	2	-10	-10					*Mach 2.78*	0.00
1358	11,26	30	"	5	"	"	"	"	3	-15	-10					*Mach 2.78*	0.00
1400	12,27		"	"	"	"	"	"		"	"					*try it again: weak shock second time & third time (test point is 2nd time)*	
1402	13,28		"	7.5	"	"	"	"		-12.5	-7.5					*no flow, M2.18*	0.00
1403	14,29		"	7.5	"	"	"	"		"	-2.5					*no flow*	0.00
1405	15,30		"	7.5	"	"	"	"		-10	"					*no flow, M2.14 (when open M1.33*	0.00
1406	16,31		"	7.5	"	"	"	"	4	-7.5	"					*flow! slow to start M2.77 (when open M1.4)*	0.00
1408	17,32		"	7.5	"	"	"	"		-5	"					*no flow, M2.10 (when open M1.32)*	0.00

Table D-17b. Dec 12: first Mach 3.0 run schedule with outputs (15th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 3.0 Calibration - Shakedown of Facility

2005: run 15   date: 12 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Vane Angle Combo (noted only if different than Main Vane Angle) IGV	Vane 1	Vane 9	Vane 10	Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
122?	1	1	2116	20												Static (pts 2-15 BL probe)	0.00
1410	18,33		"	10	"	"	"	"		-2.5	0					*this data point might have been taken early!*	0.00
1412	19,34		"	10	"	"	"	"		"	"					*close*	0.00
1415	20,35		"	10	"	"	"	"		-5	"					*close*	0.00
1417	21,36		"	10	"	"	"	"		-10	"					*FLOW!*	0.00
1419	22,37		"	10	"	"	"	"		"	-5					*no flow*	0.00
1420	23,38		"	15	"	"	"	"		-5	0					*weak shock (M1.32 when open)*	0.00
1422	24,39		"	15	"	"	"	"		"	-5					*no flow*	0.00
1424	25,40		"	15	"	"	"	"		-10	"					*FLOW!*	0.00
1426	26,41		"	15	"	"	"	"		"	0					*FLOW!*	0.00
1429	27,42		"	20	"	"	"	"		-5	5					*close*	0.00
1430	28,43		"	20	"	"	"	"		0	"					*no flow (M1.97)*	0.00
1431	29,44		"	20	"	"	"	"		5	"					*no flow (M2.66)*	0.00
1434	30,45		"	20	"	"	"	"		0	0					*no flow, close*	0.00
1436	31,46		"	20	"	"	"	"		-5	"					*flow, dewpt -31*	0.00
1438	32,47		"	20	"	"	"	"		-10	"					*close*	0.00
1442	33,48		"	15	"	"	"	"		-10	-5					*flow (M1.44 when open)*	0.00
1455	34,49		"	15	"	"	"	"		"	"					*flow (M2.84)*	0.00
1458	35,50		"	15	"	"	"	"		"	"					*Flow (M2.91)*	0.00

Table D-18a. Dec 14: second Mach 3.0 run schedule with outputs (16th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 3 Calibration - Shakedown of Facility

2005: run 16 date: 14 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													Comments		
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Vane Angle Combo (noted only if different than Main Vane Angle)				Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]	
	1	1	2116	20						IGV	Vane 1	Vane 9	Vane 10			Static *(ran BL probe TP2-21)*	0.00	
1151	2,22	2	500	-20												Synchronized *(Trip off during warm-up: restart)*	0.00	
		3	1000	15	0	11	10.5	10.5		-10	-5					*Skip*	0.00	
		4		14												*Skip*	0.00	
1253	41,20	5		13												*no flow*	0.00	
1255	42,21	6		12												*no flow*	0.00	
1256	43,22	7		11												*no flow*	0.00	
					100(open)									319	179		2.00	
1257	44,23	8		10												*no flow , dew pt -23*	0.00	
1258	45,24	9		9												*no flow*	0.00	
1259	46,25	10		8												*no flow*	0.00	
1259	47,26	11		7												*no flow*	0.00	
1300	48,27	12		6												*no flow*	0.00	
1302	49,28	13		5					11							*Mach 2.84*	0.00	
1303	50,29	14		4					12							*Mach 2.84 (or M2.78 if data taken too early)*	0.00	run with
1303	51,30	15		3					13							*Mach 2.84*	0.00	BP always
1304	52,31	16		2					14							*Mach 2.84, dew pt -21, moved Schlieren focus*	0.00	closed
1305	53,32	17		1					15							*Mach 2.84*	0.00	
1306	54,33	18		0					16							*Mach 2.84, dew pt -22*	0.00	
115?	23,3	19	1000	0	0	11	10.5	10.5	1	-10	-5					"Try to start" *Mach 2.84 (data @M2.78)*	0.00	
	24,4			0														
	25,5			0														
	26,6	20		1					2								0.00	
1201	27,7	21		2					3					241	122	*dew pt -23*	1.42	
1204	28,8	22		3					4							*Flow: started fast*	0.00	
					open									291	173	*"Jump while open" (vanes?)*	1.89	
1206	29,9	23		4												*no flow*	0.00	
1207	30,10	24		5												*no flow (M1.26 while open)*	0.00	cycle

Table D-18b. Dec 14: second Mach 3.0 run schedule with outputs (16th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 3 Calibration - Shakedown of Facility

2005: run 16 date: 14 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Vane Angle Combo (noted only if different than Main Vane Angle)				Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
	1	1	2116	20						IGV	Vane 1	Vane 9	Vane 10			Static *(ran BL probe TP2-21)*	0.00
1211	31	25		6					5								0.00
1214	32,11	26		7					6							*"Jump while on condition"*	0.00
1215	33,12	27		8												*no flow*	0.00
1217	34,13	28		9												*no flow (M1.44 while open)*	0.00
1218	35,14	29		10					7							*dew pt -27*	0.00
1225	36,15	30		11					8							*Mach2.88 (M1.35 to 1.37 open), dewpt -17*	0.00
1227	37,16	31		12					9								0.00
1229	38,17	32		13					10								0.00
1230	39,18	33		14												*no flow*	0.00
1231	40,19	34		15												*no flow*	0.00
	55,34		1000	6	0	11	10.5	10.5		-10	-5					*REPEAT ABOVE RUNS 42+*	0.00
	56,35			7													0.00
	57,36			8										287	115	*M2.85*	1.48
	58,37			9													0.00
	59,38			10													0.00
	60,39			11													0.00
	61,40			12													0.00
	62,41			13													0.00
	63,42			14												*vanes V1 (&IGV) moving!, dew pt -22.3*	0.00
	64,43			15												*(TP65-77 BL probe)*	0.00
	78,44			16													0.00
	79,45			17													0.00
	80,46			18													0.00
	81,47			19													0.00
	82,48			20													0.00
	83,49			20	20											*flow dropped out!*	0.00
																BP always closed between	

bypass open between points

Table D-18c. Dec 14: second Mach 3.0 run schedule with outputs (16th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 3 Calibration - Shakedown of Facility

2005: run 16 date: 14 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													**Comments**	
Time	**Actual Test Point #**	**Test Set Point**	**Pressure [psf]**	**Main Vane Angle**	**Bypass**	**Diffuser Walls 1&2**	**Diffuser Walls 3&4**	**Diffuser Walls 5&6**	**Schlieren Image #**	**Vane Angle Combo (noted only if different than Main Vane Angle)**				**Current on 3500 [Amps]**	**Current on 5000 [Amps]**		**Total Power [MW]**
	1	1	2116	20						IGV	Vane 1	Vane 9	Vane 10			Static *(ran BL probe TP2-21)*	0.00
		73	700	0	0%	11	10.5	10.5		-10	-5					*BP always closed between test points*	0.00
1357	99,65	78		5												"	0.00
1356	98,64	79		6												|	0.00
1355	97,63	80		7												V	0.00
1354	96,62	81		8													0.00
	84,50		700	20	0	11	10.5	10.5		-15	-10						
1345	85,51	89	700	19	0	11	10.5	10.5		-15	-10						0.00
1346	86,52	90		18													0.00
1347	87,53	91		17													0.00
1348	88,54	92		16													0.00
1349	89,55	93		15													0.00
1349	90,56	94		14													0.00
1350	91,57	95		13													0.00
1351	92,58	96		12													0.00
1351	93,59	97		11													0.00
1352	94,60	98		10													0.00
1353	95,61	99		9													0.00
?	100,66	127	700	15		11	10.5	10.5		-15	-10						0.00
?	101,67	128				10.3	8.5	8.5									0.00
1410	102,68	129				10.2	8.1	10.6									0.00
1411	103,69	130				10.2	9	9									0.00
1412	104,70	131				10.2	7.8	8.5									0.00
		143	700	15		10.2	7.8	8.5		-15	-10						0.00
1414	105,71	144	1000														0.00
1417	106,72	145	1500														0.00
1419	107,73	146	2000														0.00
1422	108,74/75	147	2500											622	308		3.62
		148	3000														0.00

Table D-18d. Dec 14: second Mach 3.0 run schedule with outputs (16th run)

Wright Patterson Tri-Sonic Gas Dynamics Facility

Mach 3 Calibration - Shakedown of Facility

2005: run 16 date: 14 Dec 05

***Bypass is CLOSED for all settings**

			Independent Variables													Comments	
Time	Actual Test Point #	Test Set Point	Pressure [psf]	Main Vane Angle	Bypass	Diffuser Walls 1&2	Diffuser Walls 3&4	Diffuser Walls 5&6	Schlieren Image #	Vane Angle Combo (noted only if different than Main Vane Angle)				Current on 3500 [Amps]	Current on 5000 [Amps]		Total Power [MW]
	1	1	2116	20						IGV	Vane 1	Vane 9	Vane 10			Static *(ran BL probe TP2-21)*	0.00
1423	109,76		2500											610	317		3.65
1424	110,77		2500											598	305		3.54
1424	111,78		2500											600	307		3.56
1425	112,79		2500														0.00
142?	113,80		2500											608	298	*end BP always closed between test pts*	3.52
	81	tunnel off															

SWITCHED? Recorded Power in range of 5MW @ end

APPENDIX E

Stress Analysis

The stress analysis was conducted by hand and on SolidWorks COSMOSXpress. The following results represent both systems on the wedge model alone and on the wedge and sting extension system. The exact material of the wedge and sting extension are not known since original prints on them are not available, but similar stings and other calibration models from the TGF, such as the pitot-static rake used for the flow calibration, are made of 17-4PH stainless steel heat treated to 180-200ksi. Due to the hardness of the wedge, it was assumed to be 17-4PH with similar heat treatments. For the calculations, an ultimate strength of 180ksi and yield strength of 155ksi was used. The loading was assumed to be maximum dynamic pressure, Q, of the tunnel 1200psf (8.33psi) and applied normal to the horizontal plane, shown in Figure E-1.

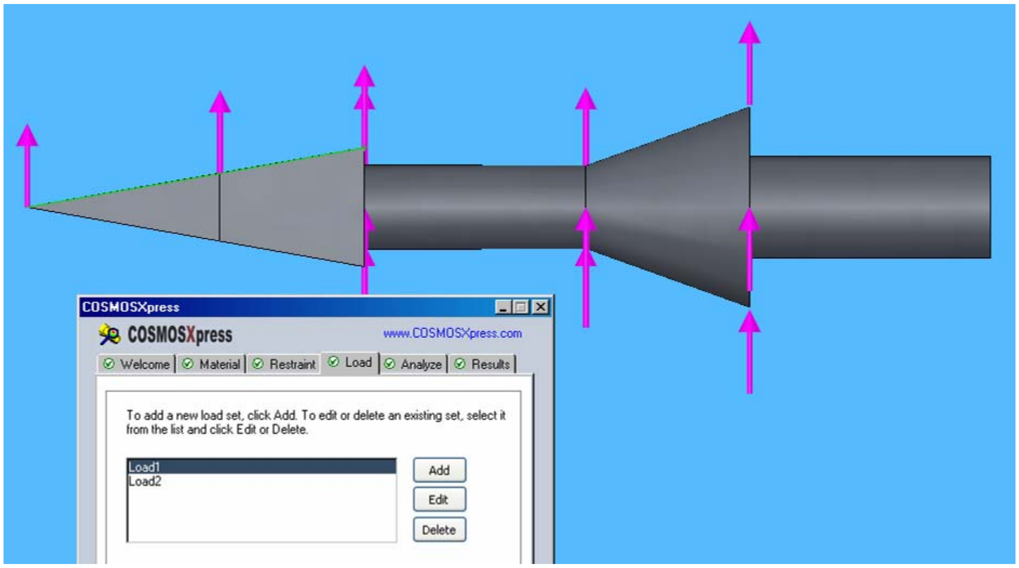


Figure E-1. Wedge loading on surfaces upstream of sting mounting

The wedge model was held into the extension sting by set screws on the end diameter. Due to the simplistic nature of COSMOSXpress, this was represented as a fixed end on the entire length of the end diameter, as shown by the green surface in Figure E-2. This gave a resulting 8.17 factor of safety, as shown in Figure E-3 which also shows the highest loading in red.

This result was compared to the unstarted condition, where a normal shock is above the model and below is an oblique shock. This gives higher loading of 10.39 psi and a resulting 6.64 factor of safety, as shown in Figure E-4.

These results were compared by hand calculations. The assumptions, free-body-diagram, reference, equations, and calculations done by hand are shown in Figure E-5a through Figure E-5g. These gave ultimate and yield factors of safety of 8.57 and 7.38 for the maximum Q and 6.84 and 5.89 for unstarted shock loading conditions.

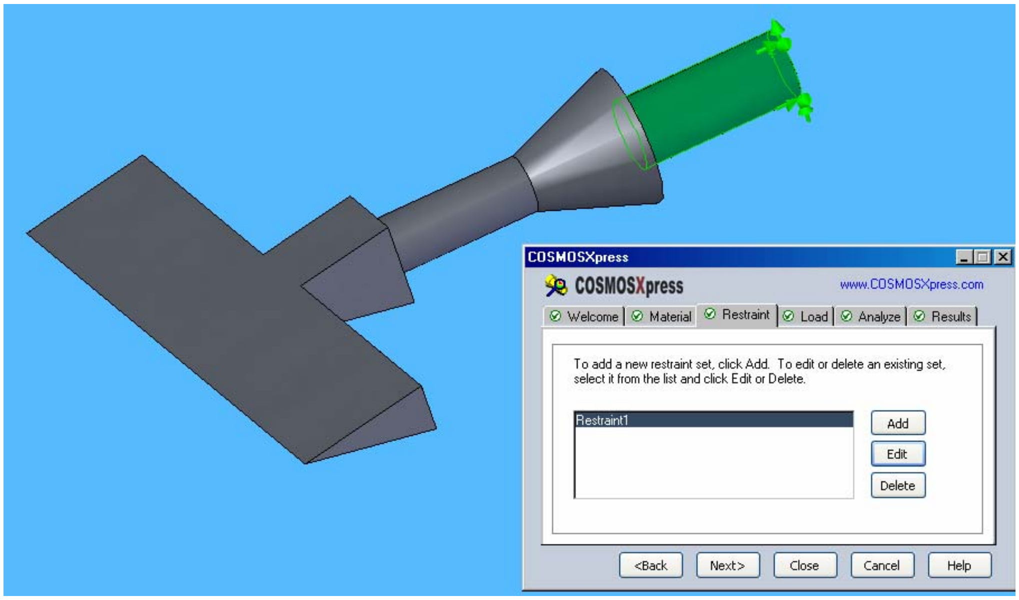


Figure E-2. Wedge restraint surface within sting mounting

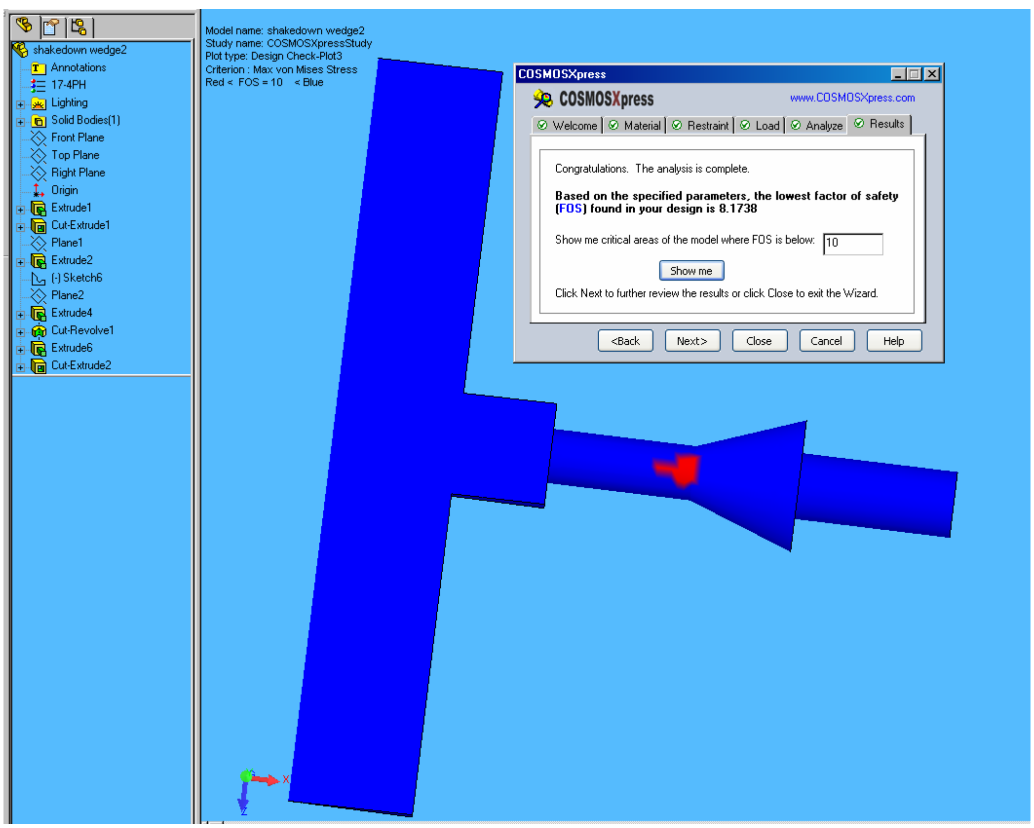


Figure E-3. Q-Loaded Resulting Factor of Safety from COSMOSXpress on wedge model

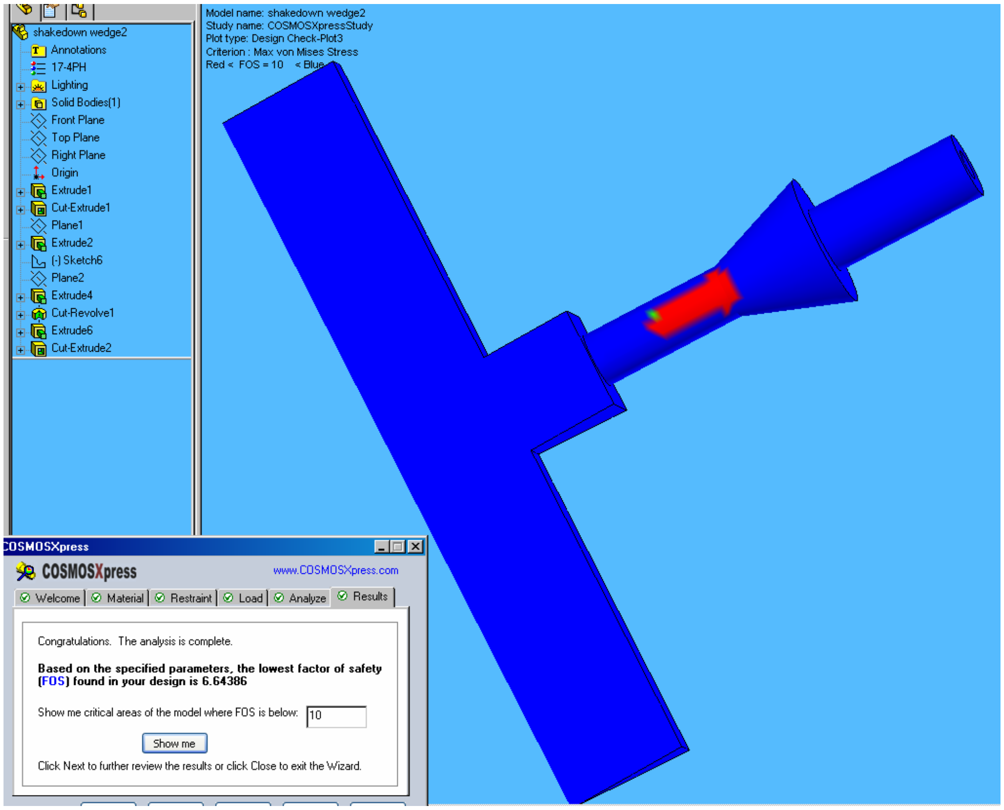
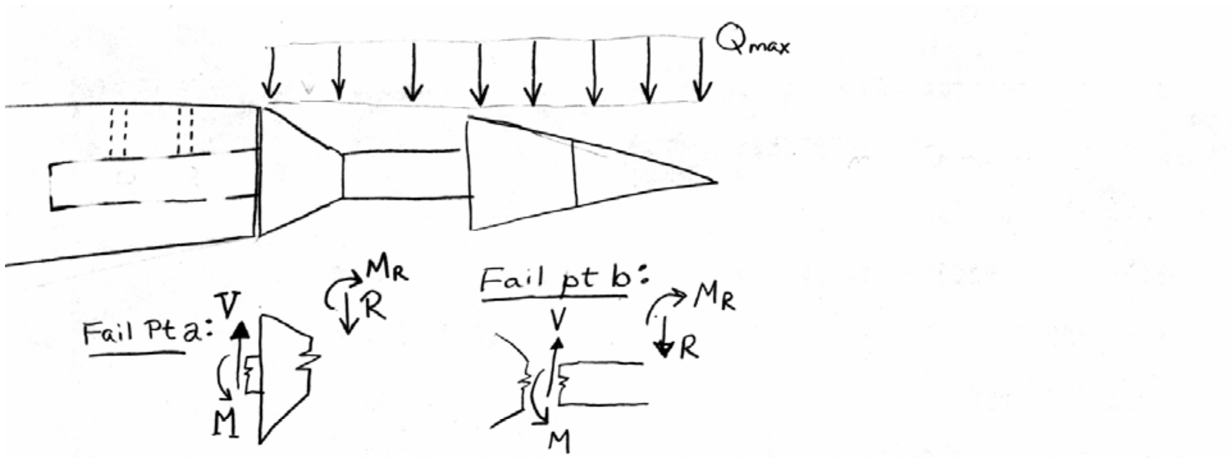


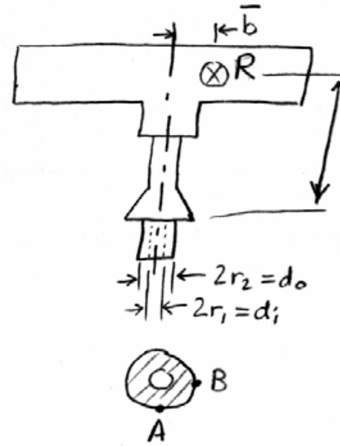
Figure E-4. Shock-Loaded Resulting Factor of Safety from COSMOSXpress on wedge model



Assume: max Q on one side only & 2 possible failure locations

Resources: Gere, J.M. Mechanics of Materials, 4th Ed. New York: PWS, 1997
Clark, Capt G.F. Trisonic Gasdynamic Facility User Manual. AFWAL-TM-82-176-FIMM.

Equations:



$$W = PA$$
$$M = PAh$$
$$V = PA$$
$$T = PA\bar{b}$$
$$\sigma_A = Md_o/(2I)$$
$$\tau_1 = Td_o/(2I_P)$$
$$\tau_2 = \frac{4V}{3A_o}\left(\frac{r_2^2 + r_2 r_1 + r_1^2}{r_2^2 + r_1^2}\right)$$

@A: $\sigma_x = 0 \quad \sigma_y = \sigma_A \quad \tau_{xy} = \tau_1$

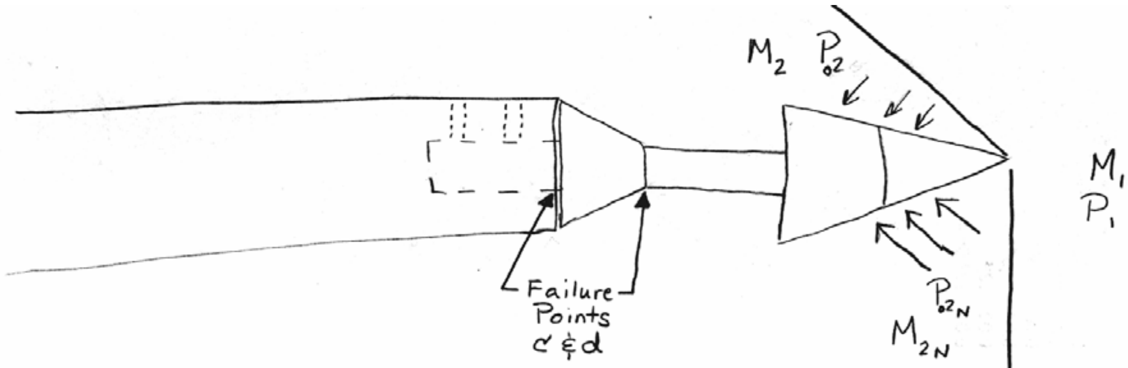
$$\sigma_{12} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\frac{(\sigma_x - \sigma_y)^2}{4} + \tau_{xy}^2}$$
$$\tau_{MAX} = \sqrt{\frac{(\sigma_x - \sigma_y)^2}{4} + \tau_{xy}^2}$$

@B: $\sigma_x = \sigma_y = 0$

$$\tau_{xy} = \tau_1 + \tau_2$$

$$FS = \sigma_{MAT'L}/(\sigma \text{ or } \tau)_{MAX}$$
$$I_{\odot} = \frac{\pi r^4}{4}$$
$$I_{P\odot} = \pi r^4/2$$

Figure E-5a. By-hand stress analysis: Assumptions and equations for maximum Q loading



Assume: 2 possible failure points

Standing / Instantaneous Shock Config, Isentropic

Resources: NACA 1135

Anderson, J.D. Fundamentals of Aerodynamics, 3rd Ed. New York: McGraw Hill, 2001.

Equations: $P_2/P_1 = 1 + \frac{2\gamma}{\gamma+1}\left(M_1^2 \sin^2\beta - 1\right)$. [1]

$M_{N_1} = M_1 \sin\beta$ [2]

Figure E-5b. Additional assumptions and equations for shock unstart loading

General Calculations:

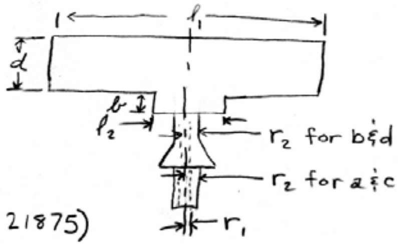
$$I_{a/c} = \frac{\pi}{4}(r_2^4 - r_1^4) = \frac{\pi}{4}(.2656^4 - .125^4) = .00372 \text{ in}^4$$

$$I_{b/d} = \frac{\pi}{4}(r_2^4 - r_1^4) = \frac{\pi}{4}(.21875^4 - .125^4) = .00161 \text{ in}^4$$

$$I_{P_{a/c}} = \frac{\pi}{2}(r_2^4 - r_1^4) = \frac{\pi}{2}(.2656^4 - .125^4) = .00744 \text{ in}^4$$

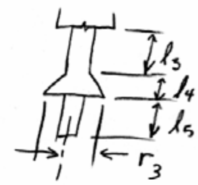
$$I_{P_{b/d}} = \frac{\pi}{2}(r_2^4 - r_1^4) = \frac{\pi}{2}(.21875^4 - .125^4) = .00322 \text{ in}^4$$

$$A = l_1 d + b\, l_2 + 2 r_{2_{b/d}}(l_3 + l_4) + 2\, l_4 (r_3 - r_{2_{b/d}})\tfrac{1}{2}$$



$$A = 6 \cdot 1 + \tfrac{3}{4}\cdot\tfrac{13}{16} + 2(.21875)(1.15 + .85) + \tfrac{2}{2}(.85)(.53125 - .21875)$$

$$A = 7.75 \text{ in}^2$$



$$h_{b/d} = \frac{d}{2} + b + l_3 = \left(\tfrac{1}{2} + \tfrac{3}{4} + 1.15\right)$$

$$h_{b/d} = 2.4 \text{ in}$$

$$h_{a/c} = h_{b/d} + l_4 = 2.4 + .85$$

$$h_{a/c} = 3.25 \text{ in}$$

$\bar{b} = 0$ [Assume even loading across surface] $\therefore T = 0$

For 17-4PH

$\sigma_{MAT'L}$: $\sigma_{yield} = 155$ksi
$\sigma_{ultimate} = 180$ksi

$$A_o = \pi(r_2^2 - r_1^2)$$

$$A_{o_{a/c}} = \pi(.2656^2 - .125^2)$$

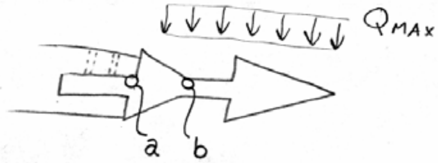
$$A_{o_{a/c}} = .1725 \text{ in}^2$$

$$A_{o_{b/d}} = \pi(.21875^2 - .125^2)$$

$$A_{o_{b/d}} = .1012 \text{ in}^4$$

Figure E-5c. Calculations for both cases

For Max Q:



$W = PA = QA$

$W = 8.33\,psi\,[7.75\,in^2]$

$W = 64.56\ lb. = V$

failure pt a

$M = PAh = Wh_a$

$M = 64.56^{\#}(3.25\,in)$

$M = 209.8\ in\text{-}lb$

$\sigma_A = M\,d_o/(2I_a)$

$= 209.8\,in\text{-}lb\,(2r_{2a})/(2 \cdot .00372\,in^4)$

$= 56398\,\frac{lb}{in^3}\,(.2656\,in)$

$\sigma_A = 14{,}979\ psi$

$\tau_1 = 0 \quad [\text{since } T = 0]$

$$\tau_2 = \frac{4V}{3A_{o_a}}\left(\frac{r_{2a}^2 + r_{2a} r_1 + r_1^2}{r_{2a}^2 + r_1^2}\right)$$

$$= \frac{4(64.56\ lb)}{3(.1725\,in^2)}\left(\frac{.2656^2 + .2656 * .125 + .125^2}{(.2656^2 + .125^2)}\right)$$

$\tau_2 = 691.3\ psi$

@A

$\sigma_x = 0 \quad \sigma_y = 14.98\,ksi$

$\tau_{xy} = 0$

$$\sigma_{12} = \frac{0 + 14.98}{2} \pm \sqrt{\left(\frac{0 - 14.98}{2}\right)^2 + 0^2}$$

$\sigma_1 = 0$

$\sigma_2 = 14.98\ ksi$

$\tau_{MAX} = 7.49\,ksi$

@B

$\sigma_x = \sigma_y = 0$

$\tau_{xy} = 691.3\,psi$

failure pt b

$M = PAh = Wh_b$

$M = 64.56^{\#}(2.4\,in)$

$M = 154.9\ in\text{-}lb$

$\sigma_A = M\,(2r_{2b})/(2I_b)$

$= 154.9\ in\text{-}lb\,(2 * .21875\,in)/(2 * .00161\,in^4)$

$\sigma_A = 21{,}046\ psi$

$\tau_1 = 0 \quad [\text{since } T = 0]$

$$\tau_2 = \frac{4V}{3A_{o_b}}\left(\frac{r_{2b}^2 + r_{2b} r_1 + r_1^2}{r_{2b}^2 + r_1^2}\right)$$

$$= \frac{4(64.56\,lb)}{3(.1012\,in^2)}\left(\frac{.21875^2 + .21875 * .125 + .125^2}{(.21875^2 + .125^2)}\right)$$

$\tau_2 = 1217\,psi$

@A

$\sigma_x = 0 \quad \sigma_y = 21.0\ ksi$

$\tau_{xy} = 0$

$\sigma_1 = 21.0\ ksi$ (see left)

$\sigma_2 = 0$

$\tau_{MAX} = 10.50\,ksi$

@B

$\sigma_x = \sigma_y = 0$

$\tau_{xy} = 1217\,psi$

Figure E-5d. Calculation of stress for maximum Q loading

For dis-similar shocks

Oblique: M_1	P_2/P_1	β
M1.5	1.56	54.3
M1.9	1.61	40.5
M2.3	1.71	33.5
M3.0	1.92	26.5

[$\frac{P_2}{P_1}$ from eq. 1 & Anderson Figure 9.7 which gives β]

Oblique Check accuracy with eq. 2 & Anderson Appendix B which gives P_2/P_1 and P_{02}/P_1 based on $Mach_{N1}$

M_1	β	M_{N1}	P_2/P_1	P_{02}/P_1
1.5	54.3	1.22	1.57	2.47
1.9	40.5	1.24	1.63	2.53
2.3	33.5	1.27	1.72	2.62 (interpolated)
3.0	26.5	1.34	1.93	2.84

From TGF User Manual

M	$P_{s\,max}$ [$= P_1$]
1.5	425 psf
1.9	425 psf
2.3	320 psf
3.0	100 psf

Normal Shock from Appendix B (Anderson) based on $Mach_1$

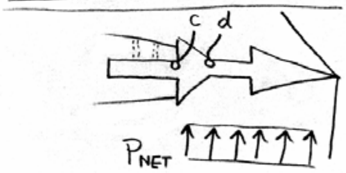
M	P_{02}/P_1
1.5	3.41
1.9	5.14
2.3	7.29
3.0	12.06

From above tables: $P_{02} = \frac{P_{02}}{P_1} P_{s\,max}$

M	P_{02} Normal Shock	P_{02} Oblique Shock	ΔP_{02}
1.5	1450.525 psf	1049.75 psf	400.775 psf
1.9	2185.35 psf	1075.25 psf	1110.10 psf
2.3	2334.08 psf	838.4 psf	1495.68 psf
3.0	1206.00 psf	284.0 psf	922.00 psf

Figure E-5e. Calculation of loading due to unstart

For disimilar shocks



Max ΔP @ M 2.3

$P_{NET} = 1496\,psf = 10.39\,psi$

$W = P_{NET} A$

$W = 10.39\,psi\,[7.75\,in^2]$

$W = V = 80.52\,lbs.$

Failure pt. c

$M = PA h_c = W h_c$

$M = 80.52\,lb(3.25\,in)$

$M = 261.7\,in\text{-}lb$

$\sigma_A = M(2r_{2c})/2I_c$

$= 261.7\,in\text{-}lb\,(2 * .2656\,in)/(2 * .00372\,in^4)$

$\sigma_A = 15472\,psi$

$\tau_1 = 0$

$\tau_2 = \frac{4V}{3A_{o_c}} \left(\frac{r_{2c}^2 + r_{2c} r_1 + r_1^2}{r_{2c}^2 + r_1^2} \right)$

$= \frac{4\,(80.52\,lb)}{3\,(.1725\,in^2)} \left(\frac{.2656^2 + .2656 * .125 + .125^2}{(.2656^2 + .125^2)} \right)$

$\tau_2 = 862\,psi$

@A:

$\sigma_x = 0 \quad \sigma_y = 15.5\,ksi \quad \tau_{xy} = 0$

$\sigma_{12} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\frac{(\sigma_x - \sigma_y)^2}{4} + \tau_{xy}^2}$

$\sigma_1 = 0$

$\sigma_2 = 15.5\,ksi$

$\tau_{MAX} = \sqrt{\frac{(\sigma_x - \sigma_y)^2}{4} + \tau_{xy}^2}$

$\tau_{MAX} = 7.75\,ksi$

@B:

$\sigma_x = \sigma_y = 0$

$\tau_{xy} = 862\,psi$

Failure pt. d

$M = PA h_d = W h_d$

$= 80.52\,lb\,(2.4\,in)$

$M = 193.25\,in\text{-}lb$

$\sigma_A = M(2r_{2d})/(2I_d)$

$= 193.25\,in\text{-}lb(2 * .21875\,in)/(2 * .00161\,in^4)$

$\sigma_A = 26257\,psi$

$\tau_1 = 0$

$\tau_2 = \frac{4V}{3A_{od}} \left(\frac{r_{2d}^2 + r_{2d} r_1 + r_1^2}{r_{2d}^2 + r_1^2} \right)$

$= \frac{4\,(80.52)}{3\,(.1012\,in^2)} \left(\frac{.21875^2 + .21875 * .125 + .125^2}{(.21875^2 + .125^2)} \right)$

$\tau_2 = 2656\,psi$

@A:

$\sigma_x = 0 \quad \sigma_y = 26.3\,ksi \quad \tau_{xy} = 0$

$\sigma_{12} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\frac{(\sigma_x - \sigma_y)^2}{4} + \tau_{xy}}$

$\sigma_1 = 0$

$\sigma_2 = 26.3\,ksi$

$\tau_{MAX} = 13.15\,ksi$

@B:

$\sigma_x = \sigma_y = 0$

$\tau_{xy} = 2.66\,ksi$

Figure E-5f. Calculation of stress for unstart loading

For Max Q:

Since σ_1 @ A for failure pt b is the maximum σ or τ, use that value to evaluate F.S.

$$FS_{yield} = \frac{155 ksi}{21.0 ksi} = 7.38$$

$$FS_{ultimate} = \frac{180 ksi}{21.0 ksi} = 8.57$$

Both are well above minimum F.S.

For Dis-similar Shocks:

σ_2 @ A for failure pt d is maximum shear or stress.

$$\sigma_2 = 26.3 ksi$$

$$FS_{yield} = \frac{155 ksi}{26.3 ksi} = 5.89$$

$$FS_{ultimate} = \frac{180 ksi}{26.3 ksi} = 6.84$$

Both are well above minimum F.S.

Figure E-5g. Factor of Safety calculations from both cases of stressing